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U.S. DEPARTMENT OF COMMERCE
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INTRODUCTION TO APRIL 1989 ISSUE OF THE CEEE TECHNICAL PROGRESS BULLETIN

This is the twenty-fifth issue of a quarterly publication providing information on the technical work of the National Institute of Standards and Technology (formerly the National Bureau of Standards) Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the fourth quarter of calendar year 1988.

Organization of Bulletin: This issue contains abstracts for all Center papers released for publication by NIST in the quarter and citations and abstracts for Center papers published in the quarter. Entries are arranged by technical topic as identified in the table of contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication". Papers published in the quarter appear under the subheading "Recently Published". Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Center conferences and workshops planned for calendar years 1989 and 1990 and a list of sponsors of the work.

Center for Electronics and Electrical Engineering: Center programs provide national reference standards, measurement methods, supporting theory and data, and traceability to national standards.

The metrological products of these programs aid economic growth by promoting equity and efficiency in the marketplace, by removing metrological barriers to improved productivity and innovation, by increasing U. S. competitiveness in international markets through facilitation of compliance with international agreements, and by providing technical bases for the development of voluntary standards for domestic and international trade. These metrological products also aid in the development of rational regulatory policy and promote efficient functioning of technical programs of the Government.

The work of the Center is divided into two major programs: the Semiconductor Technology Program, carried out by the Semiconductor Electronics Division in Gaithersburg, MD, and the Signals and Systems Metrology Program, carried out by the Electrosystems Division in Gaithersburg and the Electromagnetic Fields and Electromagnetic Technology Divisions in Boulder, CO. Key contacts in the Center are given on the back cover; readers are encouraged to contact any of these individuals for further information. To request a subscription or for more information on the Bulletin, write to CEEE Technical Progress Bulletin, National Institute of Standards and Technology, Metrology Building, Room B-358, Gaithersburg, MD 20899 or call (301) 975-2220.

Center sponsors: The Center Programs are sponsored by the National Institute of Standards and Technology and a number of other organizations, in both the Federal and private sectors; these are identified on page 39.

Note on Publication Lists: Guides to earlier as well as recent work are the publication lists covering the work of each division. These lists are revised and reissued on an approximately annual basis and are available from the originating division. The current set is identified in the Additional Information section, page 36.

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SEMICONDUCTOR TECHNOLOGY PROGRAM

Silicon Materials

Released for Publication

Bouldin, C.E., **EXAFS Study of a Buried Germanium Layer in Silicon.**

EXAFS measurements are made of a 200 Å layer of Ge on a Si substrate. The Ge layer is covered by a 3000 Å layer of SiO_2. Sensitivity to the buried layer is enhanced through the use of grazing-incidence fluorescence detection. A two-channel photodiode detector is used to detect the fluorescence and to discriminate against Bragg peaks from the single-crystal Si substrate. Since the fluorescence signal is isotropic while the Bragg peaks are directional, one channel of the detector is always free of Bragg-peak interference. We determine the average number of Ge-Ge and Ge-Si neighbors in the buried Ge layer, the distances, and disorder in the first-shell. Prospects for studying the buried Ge-SiO_2 interface are discussed.
[Contact: Charles E. Bouldin, (301) 975-2046]

Kopanski, J.J., Albers, J., and Carver, G.P., **Experimental Verification of the Relation Between Two-Probe and Four-Probe Resistances.**

Recent innovations in the measurement of two-probe (spreading resistance) and four-probe resistance using an array of lithographically fabricated, geometrically well-defined contacts have enabled the measurement of these quantities with high accuracy and reproducibility. This has permitted experimental verification of the relationship between the two-probe resistances and the four-probe resistance. Verification was also made of the predicted dependence of the four-probe resistance on the ratio of wafer thickness to probe spacing for in-line and square probe configurations.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Thurber, W.R., Lowney, J.R., Larrabee, R.D., Talwar, P., and Ehrstein, J.R., **An ac Impedance Method for High Resistivity Measurements of Silicon.**

An ac impedance method for measuring the average bulk resistivity of ingots and slices of high-resistivity silicon is described. Easily removable contacts, such as silver paste, are applied to the end faces of the sample and the impedance of the resulting capacitive sandwich is measured as a function of frequency. The resistivity can be calculated from the frequency of the negative peak in the imaginary part of the impedance and model consistency can be checked by comparison of values of resistance obtained from real and imaginary parts at this peak. Comparisons with van der Pauw and four-probe measurements are consistent with this impedance method.
[Contact: W. Robert Thurber, (301) 975-2057]

Recently Published

Geist, J., Migdall, A., and Baltes, H.P., **Analytic Representation of the Silicon Absorption Coefficient in the Indirect Transition Region**, Applied Optics, Vol. 27, pp. 3777-3779 (September 15, 1988).

An eleven-parameter equation is presented to describe the 298-K experimental silicon absorption coefficient data of Weakliem and Redfield from 1.05 eV to 2.7 eV. The standard deviation of the difference between one and the ratio of the values calculated from this equation to the Weakliem and Redfield experimental values for the same photon energies is 2.5 percent.
[Contact: Jon Geist, (301) 975-2066]

Roitman, P., and Davis, G.E., **Selected Area Channeling Pattern and Defect Etch Study of Silicon Implanted with Oxygen,** Microbeam Analysis - 1988 (Proceedings

Silicon Materials (cont'd.)

of the Materials Analysis Society, Milwaukee, Wisconsin, August 8-12, 1988), pp. 456-458.

Silicon films on buried oxide layers formed by oxygen implantation have been studied using selected area channeling patterns and chemical etching. Neither technique provides the detailed information on defect morphology available from cross-sectional transmission electron microscopy, but both techniques appear capable of providing useful information on defect densities. Sample preparation is certainly easier for both than for transmission electron microscopy, and the channeling pattern approach is nondestructive. There is some promise that they can be extended in the case of lower defect densities, although it is not clear how far. The analysis of the channeling pattern data and the correlation of that analysis with film quality need to be more firmly established.
[Contact: Peter Roitman, (301) 975-2077]

Analysis Techniques

Recently Published

Chi, P., Simons, D.S., and Roitman, P., **Artifacts Observed in Oxygen Profiles of SIMOX Samples by Secondary Ion Mass Spectrometry**, Microbeam Analysis - 1988 (Proceedings of the 22d Annual Conference of the Materials Analysis Society), Milwaukee, Wisconsin, August 8-12, 1988, pp. 121-122.

The change in oxygen secondary ion signal during depth profiling of a buried oxide layer has been observed by secondary ion mass spectrometry. The variation is due to charging of the sample during the experiment even when an electron gun is used for charge neutralization. The magnitude of the artifacts can be minimized if the analysis area is as close as possible to, and vertically displaced from, the tuning region.
[Contact: Peter Roitman, (301) 975-2077]

Gladden, W.K., Baghdadi, A., Slaughter, S., and Duncan, W., **Semiconductor Measurement Technology: Automatic Determination of the Interstitial Oxygen Content of Silicon Wafers Polished on Both Sides**, NIST Special Publication 400-81 (November 1988).

This Special Publication contains a FORTRAN and a PASCAL computer program which implement an ASTM test method for the automatic determination of the interstitial oxygen content of silicon. The programs are to be used as illustrative examples by programmers wishing to implement the ASTM algorithm on their computers. The publication also includes sample data that can be used to test the computer programs. The sample data are included in two forms: in print, and on an MS-DOS floppy disk.
[Contact: Aslan Baghdadi, (301) 975-2062]

Simons, D.S., Chi, P., Downing, R.G., Ehrstein, J.R., and Knudsen, J.F., **Progress Toward a Semiconductor Depth-Profiling Standard**, Proceedings of the Secondary Ion Mass Spectrometry Conference, SIMS-VI, Versailles, France, September 13-17, 1987, pp. 433-436 (1988).

Preamorphization of a silicon wafer by a three-stage implantation of ^{28}Si followed by ^{10}B implantation at 50 keV produces a boron distribution that varies smoothly with depth and that agrees well with a Monte Carlo calculation. This material is a suitable candidate for a SIMS depth profiling standard. Although neutron depth profiling can be used to measure the implant dose, it is inadequate, as currently applied, to follow the profile shape accurately.
[Contact: James R. Ehrstein, (301) 975-2060]

Photodetectors

Released for Publication

Geist, J., and Baltes, H., **High Accuracy Modeling of Photodiode Quantum Efficiency.**

We propose a new silicon photodiode model that is optimized for high-accuracy measurement applications. The new model differs from previous models in that the contribution from the diode front-region to the quantum efficiency is described by an integral transform of the equilibrium minority carrier concentration. This description is accurate provided that the recombination of excess minority carriers in the front region occurs only at the front surface and that the diode is operating in the linear-response region.
[Contact: Jon Geist, (301) 975-2066]

Recently Published

Geist, J., Migdall, A., and Baltes, H.P., **Analytic Representation of the Silicon Absorption Coefficient in the Indirect Transition Region**, Applied Optics, Vol. 27, pp. 3777-3779 (September 15, 1988).

An eleven-parameter equation is presented to describe the 298-K experimental silicon absorption coefficient data of Weakliem and Redfield from 1.05 eV to 2.7 eV. The standard deviation of the difference between one and the ratio of the values calculated from this equation to the Weakliem and Redfield experimental values for the same photon energies is 2.5 percent.
[Contact: Jon Geist, (301) 975-2066]

Power Devices

Recently Published

Blackburn, D.L., **A Review of Thermal Characterization of Power Transistors**, Proceedings 1988, Fourth Annual IEEE Semiconductor Thermal & Temperature Measurement Symposium (SEMI-THERM), San Diego, California, February 10-12, 1988, pp. 1-7.

The thermal characteristics of power transistors and their measurement are discussed. Topic areas addressed include general methods for measuring device temperature, control of the thermal environment, selection of a temperature-sensitive electrical parameter, measurement of temperature-sensitive electrical parameters, reasons for measuring temperature, and temperature measurement of integrated power devices. Procedures for detecting nonthermal switching transients, extrapolation of the measured temperature to the instant of switching, and for measuring the temperature of Darlington transistors are included.
[Contact: David L. Blackburn, (301) 975-2068]

Hefner, A.R., **Analytical Modeling of Device-Circuit Interactions for the Power Insulated Gate Bipolar Transistor (IGBT)**, Conference Record of the IEEE Industry Applications Society Annual Meeting, Pittsburgh, Pennsylvania, October 2-7, 1988, pp. 606-613.

The device-circuit interactions of the power Insulated Gate Bipolar Transistor (IGBT) for a series resistor-inductor load, both snubbered and unsnubbered, are simulated. An analytical model for the transient operation of the IGBT, previously developed, is used in conjunction with the load circuit state equations for simulations. The simulated results are compared with experimental results for all conditions. Devices with a variety of base lifetimes are studied.

For the fastest devices studied (base lifetime = 0.3 μs), the voltage overshoot of the series resistor-induction load circuit approaches the device voltage rating (500 V) for load inductances greater than 1 μH. For slower devices, though, the voltage overshoot is much less, and a larger

Power Devices (cont'd.)

inductance can therefore be switched without a snubber circuit (e.g., 80 μH for a 7-μs device). In this study, the simulations are used to determine the conditions for which the different devices can be switched safely without a snubber protection circuit. Simulations are also used to determine the required values and ratings for protection circuit components when protection circuits are necessary.
[Contact: Allen R. Hefner, (301) 975-2071]

Hefner, A.R., and Blackburn, D.L., **An Analytical Model for the Steady-State and Transient Characteristics of the Power Insulated Gate Bipolar Transistor**, Solid-State Electronics, Vol. 31, No. 10, pp. 1513-1532 (May 17, 1988).

An analytical model for the power Insulated Gate Bipolar Transistor (IGBT) is developed. The model predicts the IGBT steady-state current-voltage characteristics and switching transient current and voltage waveforms for all practical loading conditions. The model is based on the equivalent circuit of a MOSFET which supplies the base current to a low-gain, high-level injection, bipolar transistor with its base virtual contact at the collector end of the base. The basic element of the model is a detailed analysis of the bipolar transistor which uses ambipolar transport theory and does not assume a quasi-static condition for the transient analysis. This analysis differs from the previous bipolar transistor theory in that 1) the relatively large base current which flows from the collector end of the base is properly accounted for, and 2) the component of current due to the changing carrier distribution under the condition of a moving collector-base depletion edge during anode voltage transitions is accounted for. Experimental verification of the model using devices with different base lifetimes is presented for the on-state current-voltage characteristics, the steady-state saturation current, and the current and voltage waveforms for the constant voltage transient, the inductive load transient, and the series resistor-inductor load transient.
[Contact: Allen R. Hefner, (301) 975-2071]

Integrated Circuit Test Structures

Released for Publication

Wilson, C.L., Khera, D., Zaghloul, M.E., and Linholm, L.W., **Using Neural Techniques for Classification of Sparsely Sampled Noisy Data.**

Kohonen's LVQ method of supervised learning is used to classify sparsely sampled data containing high levels of noise. The convergence of this method and its ability to generate near optimal class separations for data of this kind are demonstrated. Data used in this classification test were obtained from measurements used to monitor a VLSI semiconductor manufacturing process. For the semiconductor manufacturing data considered here, the LVQ method, with properly adjusted gain, produced 84.4% classification accuracy without manual intervention and allows direct identification of noisy data. If errors in the training set caused by noise are corrected, 95.5% accuracy is achieved.
[Contact: Dheeraj Khera, (301) 975-2240]

Recently Published

Schafft, H.A., Lechner, J., Sabi, B., and Smith, R., **How Good Are Your Estimates of t_{50} and σ?**, Proceedings of the 1987 Wafer Reliability Workshop, O.D. Trapp, Ed., Lake Tahoe, California, October 25-28, 1987, pp. 165-174.

A transcript of a talk concerning statistics for electromigration testing is presented. The talk serves as a forerunner of a paper published in the Proceedings of the 26th Annual Reliability Physics Symposium, April 11-14, 1988.

IC Test Structures (cont'd.)

[Contact: Harry A. Schafft, (301) 975-2234]

Device Physics and Modeling

Released for Publication

Seiler, D.G., Ward, G.B., Justice, R.J., Koestner, R.J., Goodwin, M.W., Kinch, M.A., and Meyer, J.R., **Shubnikov-de Haas Measurements on n-Type and p-Type HgTe-CdTe Superlattices.**

Oscillatory magnetoresistance (Shubnikov-de Haas) measurements have been used to determine free carrier effective masses in HgTe-CdTe superlattices. Measurements on an n-type superlattice yield an electron mass which is in excellent agreement with theoretical results from tight-binding band structure calculation. The p-type data are more complex, showing evidence for a light hole mass at low magnetic fields and a much heavier mass at fields above 20 kG. This finding is also in agreement with the predictions of band structure theory.
[Contact: David G. Seiler, (301) 975-2074]

Recently Published

Lowney, J.R., **Application of Multiscattering Theory to Impurity Bands in Si:As,** Journal of Applied Physics, Vol. 64, No. 9, pp. 4544-4548 (November 1, 1988).

Impurity bands in arsenic-doped silicon have been calculated for doping densities of 3.3×10^{17}, 1.2×10^{18}, and 8.0×10^{18} cm^{-3}. A multiscattering approach is used with a model potential which provides both electronic screening and the proper bound-state energy for the isolated center. The results are in good agreement with previous calculations based on electron hopping among hydrogenic centers. An advantage of the multiscattering approach is that it treats the conduction-band states as well, and shows the loss of these states to the formation of the impurity band. Calculations are also performed for the states associated with the binding of an extra electron to un-ionized arsenic centers, the so-called D^- band. The overall results are in good agreement with the observed Mott transition in Si:As.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Lowney, J.R., **The Effect of High Injection on the Density of States of Silicon**, Proceedings of the IEEE Bipolar Circuits and Technology Meeting, Minneapolis, Minnesota, September 12-13, 1988, pp. 188-190.

The density of states of the conduction and valence bands of silicon has been calculated at 300 K for the case of an electron-hole plasma which occurs at high injection levels in bipolar devices.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Lowney, J.R., and Kahn, A.H., **Valence-Band Effective Masses of GaAs**, Journal of Applied Physics, Vol. 64, No. 1, pp. 447-449 (July 1, 1988).

The density-of-states effective masses for the heavy-hole, light-hole, and split-off valence bands of GaAs have been calculated as a function of energy in each band. The calculations are based on the theory of Dresselhaus, Kip, and Kittel with matrix elements determined by the method of Cardona. The most recent values for these matrix elements are used. Provision has been made for the effect of the split-off energy on the matrix elements of the split-off band. The results show important nonparabolicities which should be taken into account in modeling the valence band.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Mayo, S., and Lowney, J.R., **Lattice Relaxation in Silicon Doped with 4d-**

Device Physics and Modeling (cont'd.)

and 5d-Transition Metals, Journal of Applied Physics, Vol. 64, No. 9, pp. 4538-4543 (November 1, 1988).

Photoionization cross-section spectra from deep centers in silicon doped with technologically important 4d- and 5d-transition elements were analyzed by the Ridley and Amato lattice coupling model to determine threshold energy and lattice relaxation parameters corresponding to optically induced transitions involving either band. The average optic phonon energy is 50 meV. Electron transitions to the conduction band from the silver, platinum, and gold acceptor centers have, respectively, threshold energies (in meV) E_{To} = 550, 226, and 570. For silver and gold, the Huang-Rhys parameter S could not be determined because of a mixture of both allowed and forbidden transitions; for platinum, S = 0.3. Hole transitions from the valence band to the same centers have, respectively, E_{To} = 580, 905, 590, and S = 1.3, 0.5, 0.8. Hole transitions from the valence band to the donor centers of these elements are, respectively, E_{To} = 340, 320, 335, and S = 1.2, 1.4, 0.4. E_{To} and S values are uncertain to within ±5 meV and ±0.05, respectively. Electron transition data from the donor centers of these elements to the conduction band are not available or insufficient to allow analysis of the threshold region.
[Contact: Santos Mayo, (301) 975-2045]

Insulators and Insterfaces

Released for Publication

Dumin, D.J., Dabral, S., Freytag, M., Robertson, P.J., Carver, G.P., and Novotny, D.B., **Growth Properties of High-Quality Very-Thin SOS Films.**

The increased emphasis on submicron geometry CMOS/SOS devices has created a need for high-quality silicon-on-sapphire films with thicknesses of the order of 0.1 to 0.2 μm. To date, the only viable way of producing high-quality SOS films with these thicknesses has been through the application of recrystallization and regrowth techniques. The need for as-grown, high-quality, very-thin SOS films has prompted a study of film quality versus growth rate for films with thicknesses in the 0.1- to 0.2-μm range as a possible way of producing thin high-quality SOS films. It has been found that film quality increased as the growth rate increased. It was possible to produce films as thin as 0.1 μm with mobilities nearly as high as 1-μm films, if the film growth rate was higher than 4 μm/min.
[Contact: Donald B. Novotny, (301) 975-2699]

Dumin, D.J., Dabral, S., Freytag, M., Robertson, P.J., Carver, G.P., and Novotny, D.B., **High Mobility CMOS Transistors Fabricated on Very Thin SOS Films.**

The increased emphasis on submicron geometry CMOS/SOS devices has created a need for high-mobility CMOS transistors fabricated on high-quality films with thicknesses of the order of 0.1 to 0.2 μm. To date, the only demonstrated way of producing high-mobility transistors on very thin, high-quality SOS films in this thickness range has been to apply recrystallizations and regrowths to the films prior to transistor fabrication. It has been found that the mobility of CMOS transistors fabricated on very thin SOS films is a function of film growth rate. Transistors with mobilities nearly as high as those obtained on 1.0-μm thick films have been fabricated on SOS films 0.2 μm thick that have been grown at growth rates above 4 μm/min.
[Contact: Donald B. Novotny, (301) 975-2699]

Kopanski, J.J., Albers, J., and Carver, G.P., **Experimental Verification of the Relation Between Two-Probe and Four-Probe Resistances.**

Insulators and Interfaces (cont'd.)

Recent innovations in the measurement of two-probe (spreading resistance) and four-probe resistance using an array of lithographically fabricated, geometrically well-defined contacts have enabled the measurement of these quantities with high accuracy and reproducibility. This has permitted experimental verification of the relationship between the two-probe resistances and the four-probe resistance. Verification was also made of the predicted dependence of the four-probe resistance on the ratio of wafer thickness to probe spacing for in-line and square probe configurations.
[Contact: Joseph J. Kopanski, (301) 975-2089]

Recently Published

Bouldin, C.E., Bunker, G., McKeown, D.A., Forman, R.A., and Ritter, J.J., **Multiple Scattering in the X-Ray-Absorption Near-Edge Structure of Tetrahedral Ge Gases**, Physical Review B, Vol. 38, No. 15, pp. 10816-10819 (1988).

X-ray absorption fine structure (XAFS) measurements of $GeCl_4$, GeH_3Cl, and GeH_4 are made. XANES is x-ray absorption near-edge structure. Since wide-angle multiple scattering involving H atoms is negligible, we experimentally isolate the single- and multiple-scattering terms in the XAFS of $GeCl_4$. We find that multiple scattering (MS) is nowhere dominant over single scattering (SS), although within 15 eV of the absorption edge the two are comparable in size. However, the multiple-scattering term damps out very quickly with increasing energy above the edge. Above 40 eV past the edge, the MS/SS ratio is less than 0.06. Calculations are found to be in qualitative agreement with experiment, but they overestimate the size and energy range of MS. Our results suggest that XAFS data in the range $1 < k < 3$ $Å^{-1}$ can be analyzed in an SS picture in many cases, so long as good standard compounds are used, and calculations are used to estimate possible errors due to neglect of MS. We also report the first evidence of single scattering observed from H atoms.
[Contact: Charles E. Bouldin, (301) 975-2046]

Candela, G.A., Chandler-Horowitz, D., Marchiando, J.F., Novotny, D.B., Belzer, B.J., and Croarkin, M.C., **Standard Reference Materials: Preparation and Certification of SRM-2530, Ellipsometric Parameters Δ and ψ and Derived Thickness and Refractive Index of a Silicon Dioxide Layer on Silicon**, NIST Special Publication 260-109 (October 1988).

A Standard Reference Material, SRM-2530, has been designed, fabricated, and certified for the ellipsometric parameters delta, Δ, and psi, ψ, and for the derived thickness and refractive index of a silicon dioxide layer on silicon using a highly accurate ellipsometer built at NIST. This SRM is issued primarily to evaluate the accuracy of ellipsometers. The SRM consists of a 76-mm (three-inch) diameter silicon wafer with a silicon dioxide layer of one of three uniform thicknesses, 50, 100, or 200 nm. The design and fabrication of the SRM are presented along with the ellipsometric technique and data analysis leading to certification of this SRM. A least-squares method minimizing the deviations in Δ and ψ between the experimental values and those calculated from a model has been used in certifying the SRM. The derived values of the thickness and refractive index may be determined by using either a two-layer or a one-layer model. The two-layer model consists of a silicon dioxide layer on a thin interlayer atop the silicon substrate, whereas the one-layer model assumes a single dielectric layer for the silicon dioxide without the interlayer. The two-layer modeling analysis gives better agreement to the collective multiple-sample experimental data than does the

Insulators and Interfaces (cont'd.)

one-layer modeling analysis, and gives a value for the refractive index of the silicon dioxide layer that is independent of thickness. Therefore, the certified values of thickness and refractive index are based on the two-layer model.
[Contact: Deane Chandler-Horowitz, (301) 975-2084]

Dutta, P., Candela, G.A., Chandler-Horowitz, D., Marchiando, J.F., and Peckerar, M.C., **Nondestructive Characterization of Oxygen-Ion-Implanted Silicon-on-Insulator Using Multiple-Angle Ellipsometry**, Applied Physics Letters, Vol. 64, No. 5, pp. 2754-2756 (September 1, 1988).

Silicon-on-insulator formed by high-dose and high-energy oxygen-ion implantation in silicon, SIMOX, has been characterized nondestructively by multiple-angle ellipsometry using a He-Ne laser at 632.8 nm. A multilayered model exhibiting two interlayers, one between the top silicon and the buried oxide and the other between the buried oxide and the substrate silicon, offers a good representation of SIMOX. The distinction between two-temperature furnace anneal (1150°C) and high-temperature rapid thermal anneal (1150°C + 1350°C) on as-implanted wafers is manifested in terms of the optical properties of these transition regions. It is shown that the agreement between the theoretical model and the experimental results improves for the high-temperature-annealed SIMOX.
[Contact: Deane Chandler-Horowitz, (301) 975-2084]

Other Semiconductor Metrology Topics

Recently Published

Novotny, D.B., **Emission Spectra of a Diazide Photoresist Initiator and Exposure Reciprocity**, Journal of the Electrochemical Society, Vol. 135, No. 3, pp. 774-775 (March 1988).

The emission spectra of an initiator typical of those used in negative photoresists, namely, 2,6 bis-(p-azidobensilidene)-4-ethylcyclohexanone, were investigated. It is shown that the assumption that the large absorption band in negative photoresist is due to a single transition state is not valid. It is composed of narrow states which, in turn, implies that reciprocity failure and loss of sensitivity would occur at lower intensities than predicted. It is concluded that rapid quenching from the excited states is occurring.
[Contact: Donald B. Novotny, (301) 975-2699]

SIGNALS & SYSTEMS METROLOGY PROGRAM

FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

Released for Publication

Laug, O.B., **A High-Current, Very-Wide-Band Transconductance Amplifier**, to be published in the Proceedings of the IEEE Instrumentation/Measurement Technology Conference, Washington, D.C., April 27-29, 1989.

A new design approach for a high-current, very-wide-band transconductance amplifier is described. The approach is based on paralleling the input and output of complementary unipolar current-mirror cells. Each cell has a fixed current gain determined by the ratio of two resistors. A differential input voltage-to-current circuit drives the cell array. The design has the advantage of avoiding the need for a single low-resistance current-sensing resistor and the attendant problems inherent in such resistors. Although the concept is still under development, a prototype of the cell-based transconductance amplifier was implemented with ten positive and ten negative current cells to gain some experimental familiarity with the approach, in

Waveform Metrology (cont'd.)

addition to providing verification of computer simulation results. The prototype transconductance amplifier is dc coupled, has a 3-dB bandwidth of about 750 kHz, and can deliver up to 35 A rms at 100 kHz with an output compliance voltage of 5 V rms. Other important characteristics, such as output load regulation and dc offsets, are discussed.
[Contact: Owen B. Laug, (301) 975-2412]

Oldham, N.M., Bruce, W.F., Fu, C.M., and Smith, A.G., **An Intercomparison of AC Voltage Using a Digitally Synthesized Source**, to be published in the Proceedings of the IEEE Instrumentation/Measurement Technology Conference, Washington, D.C., April 27-29, 1989.

An ac voltage intercomparison was conducted by the National Institute of Standards and Technology (NIST) to determine the consistency of ac voltage measurements made at various standards laboratories. The transport standard used for this purpose was an NIST-developed digitally synthesized sinusoidal voltage source whose rms value is calculated by measuring the dc level of each of the steps used to synthesize the sine wave. The uncertainty of the calculated voltage at the 7-V level is typically within ±10 parts per million (ppm) from 15 Hz to 7.8 kHz. This approach represents a technique of referring ac voltage to a standard dc voltage, which is independent of the traditional thermal-voltage-converter approach. Preliminary measurements made at each of the participating laboratories agree with the calculated value to within ±20 ppm. This would indicate that, at the 7-V level in the low audio-frequency range, the ac voltage measurement techniques implemented at these laboratories are near the state of the art.
[Contact: Nile M. Oldham, (301) 975-2408]

Schoenwetter, H.K., **Recent Developments in Digital Oscilloscopes**, to be published in the Proceedings of the IEEE Instrumentation/Measurement Technology Conference, Washington, D.C., April 27-29, 1989.

This paper reviews the latest developments in digital storage oscilloscopes (DSOs), reported in the open literature. DSOs are used to digitize and store waveforms which may be compared, analyzed, and manipulated. DSO capabilities usually include programmability, automatic waveform parameter measurement, the display of pre-trigger signal activity, and waveform averaging to reduce noise and ripple.
[Contact: Howard K. Schoenwetter, (301) 975-2412]

Souders, T.M., Flach, D.R., Hagwood, C., and Yang, G., **The Effects of Timing Jitter in Sampling Systems**, to be published in the Proceedings of the IEEE Instrumentation/Measurement Technology Conference, Washington, D.C., April 27-29, 1989.

Timing jitter generally causes a bias in the amplitude estimates of sampled waveforms. Equations are developed for computing the bias in both the time and frequency domains. Two principal estimators are considered: the sample mean and the so-called Markov estimator used in some equivalent-time sampling systems. Examples are given using both real and simulated data.
[Contact: T. Michael Souders, (301) 975-2406]

Recently Published

Lagnese, J., and McKnight, R.H., **Calculation of Confidence Intervals for High-Voltage Impulse Reconstruction**, IEEE Transactions on Instrumentation and Measurement, Vol. 37, No. 2, pp. 201-206 (June 1988).

A recently described algorithm designed to calculate confidence intervals for solutions to ill-posed problems subject

Waveform Metrology (cont'd.)

to inequality constraints is applied to the calculation of confidence intervals for a high-voltage impulse distorted by a divider system. Applications of the method to measurements made with resistive and capacitive dividers illustrate its value for obtaining useful stochastic error bounds for high-voltage impulse restoration.
[Contact: John Lagnese, (301) 975-2423]

McKnight, R.H., and Lagnese, J., **Estimates of Confidence Intervals for Divider Distorted Waveforms**, Proceedings of the Fifth International Symposium on High Voltage Engineering, Braunschweig, West Germany, August 24-28, 1987, pp. 71.05-1 to 71.05-4 (December 1988).

This paper describes a method for computing confidence intervals for a high-voltage impulse distorted by a divider system. The technique is based on a recent algorithm designed to calculate confidence intervals for solutions to ill-posed problems subject to inequality constraints. Applications of the method to measurements made with a resistive divider illustrate its value for obtaining useful stochastic error bounds for high-voltage impulse restoration.
[Contact: John Lagnese, (301) 975-2423]

Cryoelectronic Metrology

Released for Publication

Moreland, J., Ono, R.H., Beall, J.A., Madden, M. and Nelson, A.J., **Superconducting Proximity Contacts Between the Surfaces of $YBa_2Cu_3O_x$ Thin Films.**

We use the squeezable electron tunneling (SET) junction technique for testing the superconducting properties of the surfaces of $YBa_2Cu_3O_x$ (YBCO) thin-film electrodes. The I-V characteristics of the SET junctions indicate that superconductor/normal metal/superconductor contacts exist between the surfaces of the electrodes when they are allowed to touch each other. As deposited and annealed, the surfaces of the electrodes are not superconducting at 4 K. Several methods are used to improve the superconducting properties of the electrodes' surfaces, including rapid thermal annealing, oxygen sputter etching, and thin Ag coating treatments. The greatest improvement occurs after deposition of a 5-nm Ag coating and subsequent rapid thermal anneal of the YBCO film. Under these conditions, it is possible to make a superconducting Josephson point contact between the surfaces of the electrodes. We believe that the Ag acts as normal-metal proximity layer effectively bridging the degraded electrodes' surfaces.
[Contact: John Moreland, (303) 497-3641]

Recently Published

Hu, Q., Mears, C.A., Richards, P.L., and Lloyd, F.L., **Measurement of Integrated Tuning Elements for SIS Mixes with a Fourier Transform Spectrometer**, International Journal of Infrared and Millimeter Waves, Vol. 9, No. 4, pp. 303-319 (1988).

Planar lithographed quasioptical mixers can profit from the use of integrated tuning elements to improve the coupling between the antenna and the superconductor-insulator-superconductor (SIS) mixer junctions. We have used a Fourier transform spectrometer with an Hg-arc lamp source as a radio-frequency (rf) sweeper to measure the frequency response of such integrated tuning elements. The SIS junction connected to the tuning element served as the direct detector for the spectrometer. This relatively quick, easy experiment can give enough information over a broad range of millimeter and submillimeter wavelengths to test both design concepts and success in fabrication. One type of tuning element, an inductive wire connected in parallel with a series

Cryoelectronic Metrology (cont'd.)

array of five SIS junctions across the terminals of a bow-tie antenna, shows a resonant response peak at 100 GHz with a 30% bandwidth. This result is in excellent agreement with theoretical calculations based on a simple L-C circuit. It also agrees very well with the rf frequency dependence of the mixer gain measured using the same structure. The other type of tuning element, an open-circuited stub connected in parallel with a single SIS junction across the terminals of a bow-tie antenna, exhibits multiple resonances at 110, 220, and 336 GHz, with bandwidths of 9 to 15 GHz. This result is in good agreement with theoretical calculations based on an open-circuited stub with small loss and small dispersion. The position and the bandwidth of the resonance at 110 GHz also agrees with the rf frequency dependence of the mixer gain measured using similar structures. [Contact: Frances L. Lloyd, (303) 497-3254]

Xizhi, L., Richards, P.L., and Lloyd, F.L., **SIS Quasiparticle Mixers With Bow-Tie Antennas**, International Journal of Infrared and Millimeter Waves, Vol. 9, No. 2, pp. 101-133 (1988).

We have designed and evaluated planar lithographed W-band superconductor-insulator-superconductor mixers with bow-tie antennas and several different radio frequency coupling structures. Both Pb-alloy and Nb-Pb-alloy junctions were used, each with $\omega R_N C >> 1$. Single junctions and series arrays of five junctions directly attached to bow-tie antennas with no additional coupling structure gave poor performance, as expected. Single junctions with inductive microstrips and five-junction arrays with parallel wire inductors gave good coupling over bandwidths of ≃5 and 25 percent, respectively. Good agreement is found between design calculations based on a simple equivalent circuit and measurements of the frequency dependence of the mixer gain. When good coupling was achieved, typical values of mixer gain G_M(DSB) ≃ 0 dB, noise T_M(DSB) ≃ 150 K, and receiver noise ≃200 K were observed. These measurements are referred to the cryostat window. When corrected for the estimated loss between the cryostat window and the antenna terminals, these values of gain are comparable to those observed for W-band waveguide mixers with immediate-frequency matching, but the noise is significantly higher. There is evidence that the ~100 K radiation from the heat shield surrounding the mixer reduces the gain and increases the noise. No systematic difference is observed between the performance of Pb(InAu)-Pb(Bi) junctions and Nb-Pb(InAu) junctions when the area of the latter is a factor of three smaller and the current density is a factor of three larger to maintain the same capacitance and resistance.
[Contact: Frances L. Lloyd, (303) 497-3254 or 3988]

Laser Metrology

Released for Publication

Scott, T.R., **NIST Optical Power Measurements**, to be published in the Proceedings of the Measurement Science Conference, Anaheim, California, January 26-27, 1989.

The measurement of optical power (that is, laser power or energy at wavelengths and power levels of interest to the fiber optic community) at NIST is based upon a standard reference calorimeter called the C-series calorimeter. The C-series calorimeter is a national reference standard for measuring absolute energy and power levels of continuous-wave laser sources over a wide range of wavelengths. Various infrared laser sources and a calibrated beamsplitter measurement system are used to compare an electrically calibrated pyroelectric radiometer (ECRP) to the C-series calorimeter. The calibrated ECRP is then used as a laboratory standard. The calibration of

Laser Metrology (cont'd.)

measurement of optical power at NIST is reviewed starting with a discussion of the primary reference standard and the associated measurement system. The system used for calibrating optical power detectors is then discussed and the associated uncertainties are identified.
[Contact: Thomas R. Scott, (303) 497-3651]

Recently Published

Scott, T.R., **NBS Laser Power and Energy Measurements**, Proceedings of the SPIE Laser Beam Radiometry, Vol. 888, pp. 48-54 (1988), (The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227), .

The National Bureau of Standards (NBS) maintains a set of electrically calibrated calorimeters designed and used for laser energy measurements. These calorimeters are used as national reference standards for the calibration of optical power and energy meters. Based on the standard calorimeters and associated measurement systems, NBS offers laser power and energy measurement services to the public at a variety of laser wavelengths and power ranges. The uncertainties associated with these measurements have recently been reevaluated.
[Contact: Thomas R. Scott, (303) 497-3651]

Scott, T.R., **NBS Standards for Optical Power Meter Calibration**, Proceedings of the DOD/ANSI/EIA Fiber Optics Standardization Symposium, Arlington, Virginia, December 7-10, 1987, pp. 224-238.

The measurement of optical power in the microwatt to milliwatt power range at the National Bureau of Standards is based upon a standard reference laser calorimeter called the C-Series calorimeter. The C-Series calorimeter, which is used as a national standard for the measurement of laser power/energy, was designed to be rugged, easy to use, and capable of measuring a wide range of laser wavelengths. This standard calorimeter, in conjunction with various laser sources and a calibrated beam-splitter measurement system, is used to calibrate transfer standards which are, in turn, used to calibrate other optical power meters. This paper reviews the operation and capabilities of this standard calorimeter and associated measurement system and summarizes the uncertainties associated with these energy calibration measurements.
[Contact: Thomas R. Scott, (303) 497-3651]

Pulse Power Metrology

Released for Publication

Kelley, E.F., and Nehmadi, M., **Fast Photography of Random Phenomena by Using an Image-Preserving Optical Delay**.

Image-preserving optical delays are described which can provide storage of an image for several hundred nanoseconds yet fit within a space of a few meters on a table top. The device has a measured resolution of from five to ten line pairs per millimeter. This device permits the photography of phenomena preceding fast, random events which serve to trigger the photographic recording instrument. The system is applied to the photography of liquid breakdown phenomena for the purposes of illustration.
[Contact: William E. Anderson, (301) 975-2423]

Olthoff, J.K., and Hebner, R.E., **Strategic Defense Initiative Space Power Systems Metrology Assessment**, to be published in the Proceedings of the 6th Symposium on Space Nuclear Power Systems, Albuquerque, New Mexico, January 9-12, 1989.

A survey of Strategic Defense Initiative (SDI) programs has been performed to

Pulse Power Metrology (cont'd.)

determine the measurement requirements of anticipated SDI space power systems. These requirements have been compared to present state-of-the-art metrology capabilities as represented by the calibration capabilities at the National Institute of Standards and Technology. Metrology areas where present state-of-the-art capabilities are inadequate to meet SDI requirements are discussed, and areas of metrology-related research which appear promising to meet these needs are examined. Particular attention is paid to the difficulties of long-term, unattended sensor calibrations, and measurement reliability.
[Contact: James K. Olthoff, (301) 975-2431]

Recently Published

Lagnese, J., and McKnight, R.H., **Calculation of Confidence Intervals for High-Voltage Impulse Reconstruction**, IEEE Transactions on Instrumentation and Measurement, Vol. 37, No. 2, pp. 201-206 (June 1988).

A recently described algorithm designed to calculate confidence intervals for solutions to ill-posed problems subject to inequality constraints is applied to the calculation of confidence intervals for a high-voltage impulse distorted by a divider system. Applications of the method to measurements made with resistive and capacitive dividers illustrate its value for obtaining useful stochastic error bounds for high-voltage impulse restoration.
[Contact: John Lagnese, (301) 975-2423]

McKnight, R.H., **Measuring Fast-Rise Impulses by Use of E-Dot Sensors**, Proceedings of the Fifth International Symposium on High Voltage Engineering, Braunschweig, West Germany, August 24-28, 1987, pp. 32.07-1 to 32.07-3 (December 1988).

Field-coupled sensors such as capacitive dividers, derivative (E-dot or B-dot) sensors and Rogowski coils are commonly used in pulse power applications. Measurement devices using E-dot sensors in combination with passive or active integrators provide broadband capability, but with limited sensitivity. The use of this category of sensor in measurements of fast-rise pulses, such as electromagnetic pulse, in power system equipment offers some advantages, such as ease of construction and versatility in installation.
[Contact: John Lagnese, (301) 975-2423]

Olthoff, J.K., and Hebner, R.E., **Strategic Defense Initiative (SDI) Space Power Systems Metrology Assessment**, Transactions of the 6th Symposium on Space Nuclear Power Systems, Albuquerque, New Mexico, January 9-12, 1989, pp. 124-127.

SDI space power requirements demand high reliability and operation over many orders of magnitude of both amplitude and time. While current technology is suitable for making many of these measurements, achieving acceptable levels of accuracy for some parameters will require considerable research and development. We have attempted to identify areas of the SDI program where the metrology requirements presently exceed state-of-the-art capabilities.
[Contact: James K. Olthoff, (301) 975-2431]

Van Brunt, R.J., **Research for Electric Energy Systems -- An Annual Report**, NISTIR 88-3886 (November 1988).

This report summarizes the technical accomplishments during fiscal year 1987 from a U.S. Department of Energy-sponsored program at the National Institute of Standards and Technology (formerly National Bureau of Standards) to provide technical support for DOE's research on electrical energy systems. Major activities associated with each of the four subtasks that constitute the program are highlighted. These include

Pulse Power Metrology (cont'd.)

research on: 1) electric field and ion measurements; 2) fundamental physical and chemical processes in commonly used gaseous dielectrics like SF_6; 3) development of advanced methods for observing and categorizing prebreakdown interfacial phenomena in liquid dielectrics; and 4) evaluation of advanced methods for characterizing transient measurements by use of step response and convolution integrals as they apply to free-standing dividers.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Antenna Metrology

Recently Published

Francis, M.H., Repjar, A.G., and Kremer, D.P., **Antenna Measurements for Millimeter Waves at the National Bureau of Standards**, Proceedings of the 10th Annual Antenna Measurement Techniques Association Meeting, Atlanta, Georgia, September 12-16, 1988, pp. 13-13 to 13-17.

For the past two years, the National Bureau of Standards (NBS) has been developing the capability to perform on-axis gain and polarization measurements at millimeter-wave frequencies from 33 to 65 GHz. This paper discusses the error analysis of antenna measurements at these frequencies. The largest source of error is insertion loss measurements. In order to make accurate insertion loss measurements, flanges on antennas need to be flat and perpendicular to the waveguide axis to within approximately 0.001 cm (0.0005 in.). In addition, waveguide screws need to be tightened with a device that supplies constant torque. For antennas with gains less than about 25 to 30 dB (probes), NBS can measure on-axis gains to within an uncertainty of 0.14 dB in the 33- to 50-GHz frequency band and within 0.16 dB in the 55- to 65-GHz frequency band using the three-antenna technique on the extrapolation range. For antennas with larger gains, NBS can measure on-axis gains to within an uncertainty of 0.21 dB in the 33- to 50-GHz frequency band and within.24 dB in the 55- to 65-GHz band using the planar near-field technique. NBS is continuing development of its measurement capabilities, including measuring probe correction coefficients required in planar near-field processing, in order to provide accurate pattern measurements at these frequencies.
[Contact: Michael H. Francis, (303) 497-5873]

Muth, L.A., and Lewis, R.L., **An Iterative Technique to Correct Probe Position Errors in Planar Near-Field to Far-Field Transformations**, NIST Technical Note 1323 (October 1988).

We have developed a general theoretical procedure to take into account probe position errors when planar near-field data are transformed to the far field. If the probe position errors are known, we can represent the measured data as a Taylor series, whose terms contain the error function and the ideal spectrum of the antenna. Then we can solve for the ideal spectrum in terms of the measured data and the measured position errors by inverting the Taylor series. This is complicated by the fact that the derivatives of the ideal data are unknown; that is, they can only be approximated by the derivatives of the measured data. This introduces additional computational errors, which must be properly taken into account. We have shown that the first few terms of the inversion can be easily obtained by simple approximation techniques, where the order of the approximation is easily specified. A more general solution can also be written by formulating the problem as an integral equation and using the method of successive approximations to obtain a general solution. An important criterion that emerges from the condition of convergence of the solution to the integral equation is that the total averaged position error must be less than some

Antenna Metrology (cont'd.)

fraction of the sampling criterion for the antenna under test.
[Contact: Lorant A. Muth, (303) 497-3703]

Newell, A.C., **Development of Near-Field Test Procedures for Communication Satellite Antennas Phase 1, Part 2**, NBSIR 87-3081 (August 1988).

Near-field planar scanning measurement techniques are developed for application to communication satellite antennas. Methods are described for determining sampling criteria, scan limits, precise beam alignment, and swept-frequency near-field data.
[Contact: Allen C. Newell, (303) 497-3743]

Wittmann, R.C., **Spherical Wave Operators and the Translation Formulas**, IEEE Transactions on Antennas and Propagation, Vol. 36, No. 8, pp. 1078-1087 (August 1988).

Translation formulas for both scalar and vector spherical wave solutions of the Helmholtz equation are developed, in a straightforward and relatively uncomplicated manner, emphasizing powerful differential operator techniques. Additionally, the expansion coefficients are given in compact integral or differential operator forms useful for analytic investigation.
[Contact: Ronald C. Wittmann, (303) 497-3326]

Microwave & Millimeter-Wave Metrology

Released for Publication

Juroshek, J.R., Hoer, C.A., Kaiser, R.F., **Calibrating Network Analyzers with Imperfect Test Ports.**

The test ports on automatic network analyzers are generally built with an impedance that matches the impedance of the calibration standards. Any impedance discontinuity at the test port interface is discouraged since unwanted modes can be produced. There has been concern that if unwanted modes exist at the test port interface, there is no assurance that they remain constant throughout the calibration process. Thus, a calibration and subsequent measurement error is possible. This report gives experimental evidence that substantial impedance discontinuities can be tolerated at the test port interface if proper calibration procedures are observed. The 50-Ω test port on one of the six ports in a dual six-port network analyzer was replaced with a 75-Ω test port. This test port was then calibrated to look like a 50-Ω test port. Measurements on various devices showed that indeed it was possible to make a 75-Ω test port indistinguishable from a 50-Ω test port.
[Contact: John R. Juroshek, (303) 497-5362]

Livingston, E.M., and Adair, R.T., **Performance Evaluation of Radiofrequency, Microwave and Millimeter Wave Power Meters**, to be published as NIST Technical Note 1310.

Measurement techniques are described for the evaluation of the electrical performance of commercially available radiofrequency (rf), microwave (mw) and millimeter-wave (mmw) power meters which use bolometric power sensors and which typically operate from 10 MHz to 26.5 GHz for an average power range of 10 μW to 10 mW, with appropriate attenuation for higher power ranges.

Power measurements at dc and low frequencies are relatively straightforward since voltage, current, and impedance are discrete entities from which values of power may be calculated through the use of Ohm's law. For radio, microwave, and millimeter-wave frequencies; however, these become complex, interactive, distributed parameters. Impedance mismatch, leakage, and nonlinear responses must also be considered. The principle of the bolometric method of measurement of

Microwave & Millimeter-Wave (cont'd.)

rf, mw, and mmw power is presented.

Techniques are described for analysis of: ranges of frequency and power, operating temperature, stability, response time, calibration factor, extended power measurement, overload protection, and characteristics of the internal power reference source. Some automated methods are discussed. Block diagrams of test setups are presented.

Sources of uncertainty in the bolometric method are analyzed.
[Contact: Eleanor M. Livingston, (303) 497-5339]

Recently Published

Clague, F.R., **The NIST Automated Coaxial Microwave Power Standard**, Proceedings of the 1989 Measurement Science Conference, Anaheim, California, January 26-27, 1989, pp. 1C-1 to 1C-14.

The national microwave power standards consist of two parts: a microcalorimeter and a bolometer mount used as the transfer standard. In the past, operation of the microcalorimeter has been slow and complicated, requiring skilled personnel. This paper details the automation of the 0.1- to 18-GHz coaxial microcalorimeter and the design of a new coaxial transfer standard. Together, these have reduced measurement time by a factor of ten. A highly skilled operator is no longer required, and largely unattended operation 24 hours a day is possible. The basic theory of operation of both devices, design considerations, some error evaluation problems, and performance results are included.
[Contact: Fred R. Clague, (303) 497-5778]

Optical Fiber Metrology

Released for Publication

Danielson, B.L., Whittenberg, C., and Drapela, T., **A Standard Reference Fiber for Calibration of Optical Time Domain Reflectometers**, to be published in the Technical Digest, Instrument Society of America Symposium, Orlando, Florida, May 1-4, 1989.

Calibration of optical time-domain reflectometers by military and industrial users can be achieved by a number of published test procedures. For some performance parameters, a particularly convenient way for establishing measurement verification and traceability to national standards is through the use of a standard reference fiber. At NIST, we have begun a program to evaluate such test lightguides. Prototype standard reference fibers have been characterized for spectral attenuation, group delay, group index and length. We describe measurement methods and tolerances for these devices.
[Contact: Bruce L. Danielson, (303) 497-5620]

Drapela, T.J., Franzen, D.L., Cherin, A.H., and Smith, R.J., **A Comparison of Far-Field Methods for Determining Mode Field Diameter of Single-Mode Fibers Using Both Gaussian and Petermann Definitions.**

An interlaboratory comparison of far-field measurement methods to determine mode field diameter of single-mode fibers was conducted among members of the Electronic Industries Association. Measurements were made on dispersion-unshifted and -shifted fibers at 1300 and 1550 nm. Results were calculated using both Petermann and Gaussian definitions. The Petermann definition gave better agreement than the Gaussian in all cases. A systematic offset of 0.52 μm was observed between methods when applied to dispersion-shifted fibers. Such an offset may be caused by limited angular collection.
[Contact: Timothy J. Drapela, (303) 497-5858]

Optical Fiber Metrology (cont'd.)

Scott, T.R., **NIST Optical Power Measurements**, to be published in the Proceedings of the Measurement Science Conference, Anaheim, California, January 26-27, 1989.

The measurement of optical power (that is, laser power or energy at wavelengths and power levels of interest to the fiber optic community) at NIST is based upon a standard reference calorimeter called the C-series calorimeter. The C-series calorimeter is a national reference standard for measuring absolute energy and power levels of continuous-wave laser sources over a wide range of wavelengths. Various infrared laser sources and a calibrated beamsplitter measurement system are used to compare an electrically calibrated pyroelectric radiometer (ECRP) to the C-series calorimeter. The calibrated ECRP is then used as a laboratory standard. The calibration of measurement of optical power at NIST is reviewed starting with a discussion of the primary reference standard and the associated measurement system. The system used for calibrating optical power detectors is then discussed and the associated uncertainties are identified.
[Contact: Thomas R. Scott, (303) 497-3651]

Recently Published

Danielson, B.L., **Calibration and Standardization Issues for the Optical Time-Domain Reflectometer**, NBSIR 87-3078 (December 1987).

We review some of the issues related to the specification and assurance of optical time-domain reflectometer (OTDR) performance. These include selection of appropriate performance parameters, definition of terms, test procedures, measurement difficulties, and use of standard reference fibers. Some recommendations are given for an OTDR calibration program.
[Contact: Bruce L. Danielson, (303) 497-5620]

Franzen, D.L., **Measurement Standards for Single-Mode Fibers**, Proceedings of the 1988 Conference on Precision Electromagnetic Measurements, Tsukuba, Japan, June 7-10, 1988, pp. 121-122.

Standard measurement procedures for single-mode fibers are reviewed. Various methods are evaluated and agreement accuracy discussed.
[Contact: Douglas L. Franzen, (303) 497-3346/5346]

Rose, A.H., Day, G.W., Lee, K.S., Tang, D., Vesser, L.R., Paptheofanis, B.J., and Whitesel, H.K., **Optical Fiber Sensors for the Measurement of Electromagnetic Quantities**, Proceedings of Sensors Expo 1988, Chicago, Illinois, September 12-16, 1988, pp. 209A-1 to 209A-3.

Sensors used for the measurement of both pulsed and ac current, voltage, and magnetic field are described. Design considerations, including the choice of components and configurations, and performance achievements are discussed. In this paper, several sensor configurations are described which are presently being used to measure current, voltage, and magnetic fields in environments where electromagnetic interference is a problem. The current and magnetic-field sensors are based on the Faraday effect either in single-mode optical fiber or in bulk glass or polycrystalline materials. The voltage sensors are based on the linear electro-optic (Pockels) effect in cubic crystalline materials.
[Contact: Allen H. Rose, (303) 497-5599]

Electro-Optic Metrology

Released for Publication

Gallawa, R.L., and Tu, Y., **Curved Rectangular Waveguides: Propagation Constants and Whispering Gallery Modes.**

Electro-Optic Metrology (cont'd.)

Two methods are used to calculate the effective refractive index for a curved rectangular two-dimensional waveguide. The first is based on Marcatili's approximate closed-form equation appropriate to large bend radius. The second method uses a conformal transformation and the WKB method. We find a method of knowing in advance the critical bend radius, below which his equations are not applicable. The method of comparison leads to an understanding of the onset of whispering gallery modes. The effective refractive index for the whispering gallery mode is shown as a function of bend radius.
[Contact: Robert L. Gallawa, (303) 497-3761]

Simpson, P.A., **Fast-Pulse Generators and Detectors for Characterizing Laser Receivers at 1.06 μm.**

A detector system is described which is capable of measuring the waveform of pulses used to calibrate laser receivers at 1.06 μm. The risetime of the system is 0.8 ns. All parts of the system are available commercially. Also described is an optical impulse generator at 1.06 μm with a risetime of less than 100 ps. This impulse generator can be used to measure the impulse response of the detector system and of the laser receiver.
[Contact: Philip A. Simpson, (303) 497-3789]

Recently Published

Danielson, B.L., and Whittenberg, C., **Interferometric Dispersion Measurements on Small Guided-Wave Structures**, Proceedings of the Conference on Lasers and Electro-Optics, CLEO '88, Anaheim, California, April 25-29, 1988, pp. 360-361.

We describe a method for obtaining dispersion properties of components in micro-optic systems. The technique is based on a Fourier analysis of the reflective signatures obtained from a coherence-domain reflectometer.
[Contact: Bruce L. Danielson, (303) 497-5620]

Day, G.W., Lee, K.S., Rose, A.H., Veeser, L.R., Papatheofanis, B.J., and Whitesel, H.K., **Optical Fiber Sensors for Electromagnetic Quantities**, Proceedings of the 34th International Instrumentation Symposium, Albuquerque, New Mexico, May 2-6, 1988, pp. 205-207.

Several sensors used for the measurement of both pulsed and ac current, voltage, and magnetic field are described. Design considerations, including the choice of components and configurations, and performance achievements are discussed.
[Contact: Gordon W. Day, (303) 497-5204]

Hale, P.D., and Day, G.W., **Stability of Birefringent Linear Retarders (Waveplates)**, Applied Optics, Vol. 27, pp. 5146-5153 (December 15, 1988).

The effects of changes in temperature, wavelength, and direction of propagation (angle of incidence) on the retardance of zero-order, multiple-order, compound "zero-order", and temperature-compensated waveplates are described in detail. A disagreement in the literature regarding the properties of a compound "zero-order" waveplate is resolved by showing that with respect to temperature and wavelength, it behaves like a true zero-order waveplate, but with respect to angle of incidence, it behaves like a multi-order waveplate. A previously proposed temperature-compensated design is shown to suffer from the same directional limitations. A new design for a retarder consisting of one element of a positive uniaxial crystal and one element of a negative uniaxial crystal is proposed. The retardance of such a waveplate would be much less sensitive to the direction of propagation, but somewhat more sensitive to temperature, than a typical compound zero-order waveplate.

Electro-Optic Metrology (cont'd.)

[Contact: Gordon W. Day, (303) 497-5204]

Hickernell, R.K., Larson, D.R., Phelan, R.J., Jr., and Larson, L.E., **Waveguide Loss Measurement Using Photothermal Deflection**, Proceedings of the Topical Meeting on Integrated and Guided Wave Optics (IGWO'88), Sante Fe, New Mexico, March 25-April 1, 1988, pp. 2636-2638.

Photothermal deflection (PTD) is introduced as a technique for measuring propagation loss in optical channel waveguides. A probe laser beam is deflected by the thermally induced refractive-index gradient due to the absorption of guided pump light. The technique is noncontact and is applicable to a wide range of channel waveguide geometries and materials, including buried guides. Scattering centers and unguided background light affect the measurement only indirectly, since the PTD signal depends on the gradient of the local temperature and not the light intensity directly.

The pump beam from a HeNe laser of 633-nm wavelength was mechanically chopped and coupled into potassium, ion-exchanged, glass waveguides. The probe beam, also of 633-nm wavelength, was focused on the substrate surface, and its deflection was measured by a silicon bicell using lock-in detection. Our measurements of the PTD signal as a function of the probe spot position agree with similar measurements performed on bulk materials by other researchers. Scans of the PTD signal as a function of distance along the waveguide yielded propagation loss measurements with lower uncertainty than scans of the scattered light intensity. The PTD technique should be useful in the study of waveguide loss mechanisms.
[Contact: Robert K. Hickernell, (303) 497-3455]

Larson, D.R., and Phelan, R.J., Jr., **Fast Optical Detector Deposited on Dielectric Channel Waveguides**, Optical Engineering, Vol. 27., No. 26, pp. 503-505 (June 1988).

We have fabricated a thin-film optical detector for detecting short optical pulses propagating in channel waveguides. The detectors show response times of 200 ps full-width-at-half-maximum amplitude when illuminated by guided, subpicosecond optical pulses.

The detectors are formed by depositing hydrogenated amorphous silicon (a-Si:H) directly on the dielectric channel waveguides. Back-to-back Schottky photodiodes are then formed when interdigitated chromium-gold metal contacts are deposited on the a-Si:H.
[Contact: Donald R. Larson, (303) 497-3440]

Larson, D.R., and Phelan, R.J., Jr., **Picosecond Pulse Response from Hydrogenated Amorphous Silicon (a-Si:H) Optical Detectors on Channel Waveguides**, Proceedings of SPIE, Integrated Optical Circuit Engineering V, Vol. 835, pp. 59-63, 1987 (The International Society for Optical Engineering).

We have fabricated high-speed optical detectors on channel waveguides formed by both potassium ion-exchange in glass and titanium diffusion in lithium niobate. These new waveguide detectors show response times of 200 ps full-width-at-half-maximum amplitude when illuminated with subpicosecond optical pulses. The detectors consist of back-to-back Schottky photodiodes formed by chromium-gold metal contacts on hydrogenated amorphous silicon (a-Si:H). Using interdigitated metal contacts with the contact separation and semiconductor film thickness dimensions close to a micrometer results in detectors that are both fast and efficient.
[Contact: Donald R. Larson, (303) 497-3440]

Larson, L.E., Larson, D.R., and Phelan, R.J., **System for Measuring Optical**

Electro-Optic Metrology (cont'd.)

Waveguide Intensity Profiles, NBSIR 3092 (August 1988).

A computer-controlled system to measure the intensity profile of optical waveguides has been developed. Knowledge of the intensity profile provides an indication of the shape of the waveguide and, therefore, the degree to which light can be coupled to the guide from an optical fiber. This report describes the construction and operation of this system.
[Contact: Donald R. Larson, (303) 497-3440]

Lee, K.S., and Day, G.W., **Effect of Multiple Internal Reflections on the Stability of Electrooptic and Magnetooptic Sensors**, Applied Optics, Vol. 27, p. 4609-4611 (November 15, 1988).

The effects of multiple internal reflections are evaluated analytically. Response functions showing changes in shape as a function of optical path length are computed. The variation in sensitivity is obtained as a function of the reflectance of the sensing element and is found to be significant (several tenths of a percent) even when the reflectance is reduced to 0.1 percent.
[Contact: Kyung Lee, (303) 497-5170]

Phelan, R.J., Jr., and Craig, R.M.,**An Electrically Calibrated Silicon Bolometer for Low Level Optical Power and Energy Measurements**, Proceedings of the SPIE, Laser Beam Radiometry, Vol. 888, pp. 38-42, 1988 (The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227).

A cryogenically cooled, silicon-on-sapphire, electrically calibrated bolometer has been designed and measured to have a noise equivalent power of 10^{-11} watts per root Hertz. Optical power measurement accuracies of 1 percent have been demonstrated.
[Contact: Robert J. Phelan, Jr., (303) 497-3696]

Complex Testing

Released for Publication

Dai, H., and Souders, T.M., **Time Domain Testing Strategies and Fault Diagnosis for Analog Systems**, to be published in the Proceedings of the IEEE Instrumentation/Measurement Technology Conference, Washington, D.C., April 27-29, 1989.

An efficient approach is presented for functional testing and parameter estimation of analog circuits in the time domain. The test equations are based on the sensitivity matrix, which can be obtained simultaneously with the nominal solution vector. Two examples are given, with results based on actual measurement data. Practical considerations, including the effects of ambiguity groups, measurement errors, and time skew are covered. The approach can be directly extended to nonlinear circuits.
[Contact: T. Michael Souders, (301) 975-2406]

Stenbakken, G.N., Souders, T.M., and Stewart, G.W., **Ambiguity Groups and Testability.**

An efficient method has been developed for determining component ambiguity groups which arise in analog circuit testing. The method makes use of the sensitivity model of the circuit. The ambiguity groupings are shown to depend on the test points selected and the measurement accuracy; the analysis is therefore a useful tool for determining where to add or delete test points. The concept of ambiguity groups can be used to refine the testability measure of a circuit.
[Contact: Gerard N. Stenbakken, (301) 975-2440]

Other Fast Signal Topics

Released for Publication

Other Fast Signal Topics (cont'd.)

Capobianco, T.E., and Dulcie, L.L., **Results of the Eddy Current Probe Characterization Round Robin**, to be published in the Proceedings of the 37th Defense Conference on Nondestructive Testing, Jacksonville, Florida, November 1-3, 1988.

A round robin was recently conducted by NIST involving potential users of a proposed new military standard. This draft standard attempts to establish a test method for characterizing eddy current probe performance. The three objectives of the study were: 1) to assess the ability of potential standard users to implement the specified test, 2) to introduce potential users to the technique, and 3) to expose any shortcomings in the test method documentation. The round robin involved 11 participants representing a spectrum covering military labs to repair depots. Preliminary results from this study were incorporated in the second draft of the standard as a result of meeting the second and third objectives. This paper will concentrate on the fact that the round-robin results show a significant problem exists with the test method implementation.
[Contact: Thomas E. Capobianco, (303) 497-3141]

Hill, D.A., **Clutter Models for Subsurface Electromagnetic Applications**, to be published as NISTIR 89-3909.

Clutter models for subsurface electromagnetic applications are discussed with emphasis on the detection of tunnels. Random medium models are more versatile and require less detailed information than deterministic models. The Born approximation is used to derive expressions for the incoherent field, and electric and magnetic dipoles are treated in detail. When random inhomogeneities are located in the near field of the dipole source, an electric dipole radiates a larger incoherent field than a magnetic dipole because of its larger reactive electric field.
[Contact: David A. Hill, (303) 497-3472]

Recently Published

Dulcie, L.L., and Capobianco, T.E., **New Standard Test Method for Eddy Current Probes**, Proceedings of the 36th Defense Conference on Nondestructive Testing, St. Louis, Missouri, October 27-29, 1987, pp. 154-160.

Recently, a draft military standard for the characterization of eddy current probes was submitted to the U.S. Army Materials Technology Laboratory by the National Bureau of Standards. We discuss the development of a standard test set and our future plans for a round-robin study for evaluating the draft standard in a controlled study. The test set will be used to determine impedance measurement capability and consists of two parts: 1) a prototype test block set as specified by the draft standard and 2) a specially designed and characterized probe set. A round-robin survey will be conducted to determine ease of use, repeatability of characterization measurements, and impedance measurement precision when using the test blocks as specified in the standard.

Round-robin participants will be military nondestructive evaluation facilities that will perform impedance measurements using the standard test set. The ability to measure impedance reliably is basic to the implementation of the standard. This reliability will be determined by a statistical analysis of measurement results received from the round-robin participants.
[Contact: Laura L. Dulcie, (303) 497-5181]

Geyer, R.G., **Dielectric Mixing Rules for Background Test Soils**, NBSIR 88-3095 (June 1988).

The bulk or effective dielectric constant of any background test medium

Other Fast Signal Topics (cont'd.)

(whether naturally occurring or synthetic) determines the electromagnetic visibility of buried objects. Heuristic mixing rules are considered that allow the prediction of complex dielectric behavior in linear, homogeneous, isotropic, and lossy multi-phase soil mixtures. Measurement results in bio-electromagnetic and microwave remote sensing suggest a refractive mixing model as that being most suited for dry soils or soil-water mixtures.
[Contact: Richard G. Geyer, (303) 497-5852]

Geyer, R.G., **Magnetostatic Measurements for Mine Detection**, NISTIR 88-3098 (October 1988).

The use of a Maxwell inductance bridge and associated calibration procedure for measuring the magnetic susceptibility of magnetically linear, homogeneous, and isotropic materials is reviewed. A complication in this measurement exists, since electromagnetic induction sensors respond to the product of the magnetic permeability and electrical conductivity. For this reason, frequency limitations resulting from sample size and conductivity must be considered. Such limitations can be specified by examining the in-phase and quadrature components of the induced dipole moment of a conductive, permeable sphere of diameter equivalent to that of the bridge test coil in a uniform alternating magnetic field and by choosing a maximum allowable test frequency that gives an induction number much less than 1 within the sphere.

Magnetic susceptibility measurements are applied to the passive magnetometric detection problem of an arbitrarily shaped susceptible (metallic) mine buried in a magnetically permeable earth. For analysis purposes, a conservative susceptibility contrast between a typical metallic mine and host soil was assumed, having the same measured magnetic characteristics as the U.S. Army Belvoir Research and Development Center magnetite-sand mine lane mixture. Anomalous detection limits were then calculated for various total-field-intensity sensor (proton precession) head heights and offset distances, given mine dimensions as small as 7.6 cm on a side.
[Contact: Richard G. Geyer, (303) 497-5852]

Hill, D.A., **Fields of Horizontal Currents Located Above the Earth**, IEEE Transactions on Geoscience and Remote Sensing, Vol. 26, No. 6, pp. 726-732 (November 1988).

The plane-wave spectrum technique is used to derive the fields of horizontal currents located in a horizontal plane above the earth. The far field is derived asymptotically, and the near field is computed by two-dimensional fast Fourier transform. Specific numerical results are presented for a pair of oppositely directed dipoles, and the results have application to detection of buried objects. When the antenna is located at low heights, the field is enhanced in the earth and decreased in air.
[Contact: David A. Hill, (303) 497-3472]

Hill, D.A., **Magnetic Dipole Excitation of a Long Conductor in a Lossy Medium**, IEEE Transactions on Geoscience and Remote Sensing, Vol. 26, No. 6, pp. 720-725 (November 1988).

Formulations for the excitation of currents on an infinitely long conductor by electric or magnetic dipoles of arbitrary orientation are presented. The conductor can be either insulated or bare to model ungrounded or grounded conductors. Specific calculations are presented for a vertical magnetic dipole source because this source produces the appropriate horizontal polarization and could be used in a borehole-to-borehole configuration. Numerical results for the induced current and secondary magnetic field indicate that long

Other Fast Signal Topics (cont'd.)

conductors produce a strong anomaly over a broad frequency range. The secondary magnetic field decays slowly in the direction of the conductor and eventually becomes larger than the dipole source field.
[Contact: David A. Hill, (303) 497-3472]

Jesch, R.L., **Fixed and Base Station FM Receivers**, U.S. Department of Justice, Technology Assessment Program, NIJ Standard-0206.01 (July 1988).

The purpose of this document is to establish performance requirements and methods of test for nontrunked, frequency-modulated (FM) fixed and base-station receivers used by law enforcement agencies. This standard applies to voice-modulated nonmultiplex receivers which either do not have special subsystems such as selective signaling or voice privacy, or in which such subsystems are bypassed or disabled during testing for compliance with this standard. This standard supersedes NILECJ-STD-0206.00, Fixed and Base Station FM Receivers, dated September 1975. This revision has been written to include receivers operating in the 806- to 866-MHz frequency band and it also provides modified requirements for receiver sensitivity, audio response, and closing time. The tests have been revised to accommodate receivers with a balanced audio output and updated to incorporate improved tests of spurious and harmonic response attenuation and intermodulation attenuation.
[Contact: Ramon L. Jesch, (303) 497-3496]

Lehman, J.H., **Cool It!**, The Science Teacher, pp. 29-32 (March 1988).

Sometimes, a well-rounded curriculum for the physical sciences is burdened with bringing into the classroom topics that do not necessarily correspond to our daily observations and intuition. Heat, energy, resistance, kinetics, and countless other topics challenge not only the student's imagination, but also an instructor's ability to present such topics in realistic and interesting ways. Cryogenics, known informally as the science of cold, offers many avenues for learning beyond the obvious effects of cold temperature. This paper includes some justification, pedagogy, and motivation for use of cryogenics in science curricula.
[Contact: John Lehman, (303) 497-3654]

Vanzura, E.J., **Creating CSUBs in BASIC**, HP Design and Automation Magazine, pp. 18-21 (October 1988) and p. 25 (November 1988).

CSUBs are compiled subprograms created using the Pascal operating system which run in the BASIC environment. A new technique is described in which programs written in FORTRAN can be turned into CSUBs. Thus, powerful, well-documented FORTRAN routines become accessible to the BASIC-language programmer. I/O and variable interfacing are discussed, and a comprehensive example is provided.
[Contact: Eric J. Vanzura, (303) 497-5752]

Young, M., **Fresnel Lenses Display Inherent Vignetting**, Applied Optics, Vol. 27, No. 17, pp. 3593-3594 (September 1, 1988).

Some of the light refracted by a facet of a Fresnel lens impinges on the axial (or horizontal) portion of the facet and is directed away from the focal point. Loss of this light may be significant in applications where precise radiometric measurements are necessary.
[Contact: Matt Young, (303) 497-3223/-5342]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Misakian, M., Anderson, W.E., and Laug, O., **Drift Tubes for Characterizing**

Power Systems Metrology (cont'd.)

Atmospheric Ion Mobility Spectra Using AC, AC-Pulse and Pulse Time-of-Flight Measurement Techniques.

Two drift tubes constructed of insulating cylinders with conductive guard rings on the inside walls are examined to determine their suitability for measuring ion mobility spectra at atmospheric pressure. One drift tube is of the pulse time-of-flight (TOF) type with adjustable drift distance and the other is an ac-TOF drift tube similar in principle to devices reported by Tyndall and Powell, and Van de Graff. The latter drift tube is evaluated using sinusoidal and alternating-polarity pulse-voltage waveforms for gating the shutters. Methods for determining the drift velocity of an ion from theoretical fits of the TOF spectrum are described for drift tubes of fixed length exhibiting "end effects." Mobility values with uncertainties less than ±1% can be obtained with the pulse-TOF drift tube. Comparable results are obtained with the ac drift tube if an alternating-polarity pulse-voltage waveform is used for gating the shutter.
[Contact: Martin Misakian, (301) 975-2426]

Olthoff, J.K., Van Brunt, R.J., Wang, Y., Champion, R.L., and Doverspike, L. D., **Collisional Electron Detachment and Decomposition Cross Sections for SF_6^-, SF_5^-, and F^- on SF_6 and Rare Gas Targets.**

Absolute cross sections for collisional electron detachment of SF_6^-, SF_5^-, and F^- on SF_6 and rare gas targets are presented for center-of-mass collision energies ranging from a few eV to several hundred eV. Onsets of collisional detachment cross sections are found to be higher than previously anticipated. Cross sections are also measured for collision-induced dissociation processes of SF_6^-, SF_5^-, and F^- in SF_6 and rare gases.
[Contact: James K. Olthoff, (301) 975-2431]

Olthoff, J.K., Van Brunt, R.J., Wang, Y., Champion, R.L., and Doverspike, L. D., **Collisional Electron Detachment and Decomposition Rates of SF_6^-, SF_5^-, and F^- in SF_6: Implications for Ion Transport and Electrical Discharges.**

Measured cross sections for prompt collisional detachment and decomposition of SF_6^-, SF_5^-, and F^- on SF_6 reported in a companion paper [See Olthoff, J.K., Van Brunt, R.J., Wang, Y., Champion, R.L., and Doverspike, L.D., "Collisional Electron Detachment and Decomposition Cross Sections for SF_6^-, SF_5^-, and F^- on SF_6 and Rare Gas Targets"] are used to calculate detachment coefficients and ion-conversion reaction coefficients as functions of electric field-to-gas density ratio (E/N) for ion drift in SF_6. The calculated detachment coefficients indicate that prompt electron detachment from SF_6^- and SF_5^- in SF_6 are insignificant processes. Calculated rates for ion-conversion processes indicate the necessity to re-examine the previously measured rates in SF_6 from drift-tube experiments, and indicate the necessity of using ion kinetic energy distributions with larger high-energy tails than the standard distributions assumed in earlier calculations. The calculated detachment and reaction coefficients are used in a theoretical model which invokes detachment from long-lived energetically unstable states of collisionally excited SF_6^- to explain the pressure dependence of previously measured detachment coefficients and the high detachment thresholds implied by analysis of electrical breakdown-probability data for SF_6. Consistent with interpretation of results from earlier work, the model indicates that at high pressure, measured detachment coefficients depend primarily upon rates for ion-conversion and prompt collisional detachment from F^-.
[Contact: James K. Olthoff, (301) 975-

Power Systems Metrology (cont'd.)

2431]

Petersons, O., **Review of book entitled, "The Current Comparator," by W.J.M. Moore and P.N. Miljanic.**

This review covers the book, "The Current Comparator," by W. J. M. Moore and P. N. Miljanic. The review includes an overall assessment of the coverage of the subject, and addresses the clarity and effectiveness of the authors in reaching their intended audience. The book is a concise, yet comprehensive monograph covering the basic principles, construction, details, error sources, and error reduction techniques for magnetic current comparators. Alternating- (power frequency) and direct-current comparators are covered. Numerous applications and instruments utilizing current comparators are described. The book serves both as tutorial material for the uninitiated and as a reference volume for the expert.
[Contact: Oskars Petersons, (301) 975-2400]

Ramboz, J.D., **High-Current Measurement Techniques, Part II, 100-kA Source Characteristics and Preliminary Shunt and Rogowski Coil Evaluations**, to be published as NISTIR 89-4040.

The characterization of a 100-kA current source is discussed. This source is intended for use in the calibration of high-current sensors such as shunts and Rogowski coils commonly employed in resistance welders. The output current from the source is derived from SCR-gated signals in the form of bursts of "chopped" 60-Hz sinusoidal waveforms. These waveforms and their spectral content were investigated. The near-field magnetic field strength was mapped. Initial calibrations were performed on a 30-kA, 10-$\mu\Omega$ shunt. Preliminary results indicate a temperature coefficient of about 130 ppm/°C which is thought to be related to a thermally induced strain. Several Rogowski-coil-type current sensors were evaluated and calibrated. Each of the coils measured had outputs which were sensitive to the rotational position about the current-carrying conductor. The calibration philosophy and approach is discussed and estimates of measurement uncertainty are given. Suggested improvements for the measurement process are offered. Planned efforts are outlined.
[Contact: John D. Ramboz, (301) 975-2434]

Recently Published

Fenimore, C., **The Thermal-Expansive Growth of Prebreakdown Streamers in Liquids**, Proceedings of the 1988 IEEE International Symposium on Electrical Insulation, Boston, Massachusetts, June 5-8, 1988, pp. 27-30.

The growth of electrically conductive, low-density regions has been observed in dielectric breakdown in a variety of liquids. This phenomenon motivates the development of the present theory for coupling thermal effects with fluid mechanical effects in the dynamics of elongated, impulsively driven bubbles. The model explicitly describes the time-dependent dimensions of a growing ellipsoidal bubble. The parameters of the model are the external pressure in the liquid, the density of energy which is deposited impulsively in the liquid, and the length over which energy is deposited.

In previous work, we have developed a model for such effects associated with the growth of a bubble about an arc in a liquid. In the case of the prebreakdown streamer, the geometry is not as simple as for an arc, and the evolution of the bubble is found in ellipsoidal coordinates. The effect of pressure is to shorten the time scale of the bubble dynamics. Even in the case when the bubble may not be spatially resolved, the time to recollapse can be established from visual data. Calcula-

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tions based on the model are shown to be consistent with experimental results on the collapse of the streamer.
[Contact: Charles Fenimore, (301) 975-2428]

Kelley, E.F., Hebner, R.E., Anderson, W.E., Lechner, J.A., and Blue, J.L., **The Effect of an Oil-Paper Interface Parallel to an Electric Field on the Breakdown Voltage at Elevated Temperatures**, IEEE Transactions on Electrical Insulation, Vol. 23, No. 2, pp. 249-259 (April 1988).

This paper reports the measurements made in a study of the electrical breakdown location in the vicinity of an oil-paper interface over the temperature range from room temperature to 150°C. The data indicate that the electrical breakdown occurred at the interface from 15% to 43% of the time, depending on the details of the particular set of measurements. A theoretical analysis shows that this experimental result is consistent with the electric field enhancement, the area over which the enhancement occurs, and the spread in the breakdown voltages for nominally identical tests.
[Contact: William E. Anderson, (301) 975-2423]

Kelley, E.F., Nehmadi, M., Hebner, R.E., Pace, M.O., Wintenberg, A.L., Blalock, T.V., and Foust, J.V., **Measurement of Partial Discharges in Hexane Under DC Voltage**, 1988 Annual Report of the Conference on Electrical Insulation and Dielectric Phenomena, Ottawa, Canada, October 16-20, 1988, pp. 394-402.

Partial discharges in liquid hexane are observed at the tip of a needle-sphere electrode system subjected to dc high voltage. A sensitive amplifier monitors the partial discharge current and activates a circuit which operates a high-speed, high-magnification photography system. The initiation and growth of the partial discharges is being photographed and correlated with the current supplied to the partial discharge. The initiation of the random phenomena is photographed by the use of an image-preserving optical delay.
[Contact: Willian E. Anderson, (301) 975-2423]

McKnight, R.H., and Lagnese, J., **Estimates of Confidence Intervals for Divider Distorted Waveforms**, Proceedings of the Fifth International Symposium on High Voltage Engineering, Braunschweig, West Germany, August 24-28, 1987, pp. 71.05-1 to 71.05-4 (December 1988).

This paper describes a method for computing confidence intervals for a high-voltage impulse distorted by a divider system. The technique is based on a recent algorithm designed to calculate confidence intervals for solutions to ill-posed problems subject to inequality constraints. Applications of the method to measurements made with a resistive divider illustrate its value for obtaining useful stochastic error bounds for high-voltage impulse restoration.
[Contact: John Lagnese, (301) 975-2423]

Misakian, M., **AC Electric and Magnetic Field Meter Fundamentals**, Proceedings of the EPRI Utility Seminar on Power Frequency and Magnetic Field Exposure Assessment, Colorado Springs, Colorado, October 12-14, 1988. pp. 1-23.

Questions raised in the early 1970s regarding possible adverse environmental effects due to high-voltage ac transmission line fields focused attention on the need for accurate measurements of the power-frequency electric and magnetic fields. Following a brief description of the fields near ac power lines, this paper surveys the instrumentation, calibration procedures, measurement techniques and standards that have been developed since the early 1970s to characterize the electric and magnetic fields near ac power lines.

Power Systems Metrology (cont'd.)

[Contact: Martin Misakian, (301) 975-2426]

Misakian, M., **Characterizing Electrical Parameters Near ac and dc Power Lines**, Proceedings of the 1988 U.S.-Japan Seminar on Electromagnetic Interference in Highly Advanced Social Systems (Modeling, Characterization, Evaluation and Protection), Honolulu, Hawaii, August 1-4, 1988, pp. 6-32 to 6-43.

During the early 1970s, reports appeared in the literature which raised questions regarding possible biological effects from exposure to power frequency lines and in substations. In response to the concerns generated by these reports, numerous bioeffects studies were initiated in the United States by government and private agencies; the studies continue to this day. In the mid-1970s, there were no standards which provided guidance for the measurement of fields near power lines or for the calibration of instrumentation used for such measurements. Today, an ANSI/IEEE standard exists for measurements of electric and magnetic fields near ac power lines, and an IEC standard exists for measuring power frequency electric fields. In addition, an IEEE standard is currently being prepared for the measurement of dc electric fields and ion-related parameters near dc power lines. This paper briefly surveys the instrumentation currently in use for characterizing fields near ac power lines, and the electric field, ion current density, and monopolar charge density near dc power lines.
[Contact: Martin Misakian, (301) 975-2416]

Misakian, M., **Measurement of Electrical Parameters Near AC and DC Power Lines**, Proceedings of the IEEE Instrumentation and Measurement Technology Conference, San Diego, California, April 19-22, 1988, p. 114.

This presentation surveys the instrumentation, calibration procedures, measurement techniques, and measurement standards which can be used for characterizing (1) fields near ac power lines and (2) electric field strength, ion current density, monopolar charge density, and net space charge near dc power lines.
[Contact: Martin Misakian, (301) 975-2426]

Phelps, A.V., and Van Brunt, R.J., **Electron Transport, Ionization, Attachment, and Dissociation Coefficients in SF_6 and Its Mixtures**, Journal of Applied Physics, Vol. 64, No. 9, pp. 4269-4277 (November 1, 1988).

An improved set of electron collision cross sections is derived for SF_6 and used to calculate transport, ionization, attachment, and dissociation coefficients for pure SF_6 and mixtures of SF_6 with N_2, O_2, and Ne.

These SF_6 cross sections differ from the previously published set primarily at very low and at high electron energies. At energies below 0.03 eV, the attachment cross section is adjusted to fit recent electron swarm experiments, while the elastic momentum transfer cross section is increased to the theoretical limit. At high energies, an allowance is made for the excitation of highly excited levels as observed in electron-beam experiments. The cross-section sets used for the admixed gases have previously been published. Electron kinetic energy distributions computed from numerical solutions of the electron-transport (Boltzmann) equation using the two-term, spherical harmonic expansion approximation are used to obtain electron transport and reaction coefficients as functions of E/N and the fractional concentration of SF_6. Here E is the electric field strength, and N is the gas number density. Attachment rate data for low concentrations of SF_6 in N_2 are used to test the attachment cross sections. Particular attention is given to the calculation of transport and

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reaction coefficients at the critical $E/N = (E/N)_c$ at which the ionization and attachment rates are equal.
[Contact: John Lagnese, (301) 975-2423]

Van Brunt, R.J., **Research for Electric Energy Systems -- An Annual Report**, NISTIR 88-3886 (November 1988).

This report summarizes the technical accomplishments during fiscal year 1987 from a U.S. Department of Energy-sponsored program at the National Institute of Standards and Technology (formerly National Bureau of Standards) to provide technical support for DOE's research on electrical energy systems. Major activities associated with each of the four subtasks that constitute the program are highlighted. These include research on: 1) electric field and ion measurements; 2) fundamental physical and chemical processes in commonly used gaseous dielectrics like SF_6; 3) development of advanced methods for observing and categorizing prebreakdown interfacial phenomena in liquid dielectrics; and 4) evaluation of advanced methods for characterizing transient measurements by use of step response and convolution integrals as they apply to free-standing dividers.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Superconductors

Released for Publication

Chen, D.-X., and Goldfarb, R.B., **Magnetization of Type-II Superconductors.**

We have calculated the initial magnetization curves and complete hysteresis loops for hard, type-II superconductors. The critical current density, J_c, is assumed to be a function of the internal magnetic field, H_i, according to Kim's model, $J_c(H_i) = k/(H_0+|H_i|)$, where k and H_0 are constants. As is the case for other critical-state models, additional assumptions are that bulk supercurrent densities are equal to J_c, and that the lower critical field is zero.

Our analytic solution is for an infinite orthorhombic specimen with finite rectangular cross section, 2a x 2b, in which a uniform field, H, is applied parallel to the infinite axis. Assuming equal flux penetration from the sides, we reduced the two-dimensional problem to a one-dimensional calculation. The calculated curves are functions of the aspect ratio of the specimen (b/a, where $b \geq a$) a dimensionless parameter = $p\ (2ka)^{1/2}/H_0$, and the maximum applied field H_m. The field for full penetration is $H_p = H_0[(1+p^2)^{1/2}-1]$. A related parameter is $H_m^* = H_0[(1+2p^2)^{-1/2}-1]$. Hysteresis loops were calculated for the different ranges of H_m: $H_m < H_p$, $H_p < H_m < H_m^*$, and $H_m^* < H_m$. The hysteresis loops are representative of experimental measurements, even at low H.

The equations for an infinite cylindrical specimen of radius a are the same as those for a specimen with square cross section, a = b. In the limit $p \ll 1$ and a = b, our results reduce to those of the Bean model (J_c independent of H_i) for cylindrical geometry. Similarly, in the limit $p \ll 1$ and $b \to \infty$, the results are the same as those for a slab in the Bean model. For $H > 1.5\ H_p$, or $H > 0$ when $p \ll 1$, the width of the hysteresis loop ΔM may be used to deduce J_c as a function of H: $J_c(H) = \Delta M(H)/[a(1-a/3b)]$.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Nikolo, M., and Goldfarb, R.B., **Flux Creep and Activation Energies at the Grain Boundaries of Y-Ba-Cu-O Superconductors.**

We measured the ac susceptibility of sintered $Y_1Ba_2Cu_3O_{7-\delta}$ pellets as a function of temperature, applied magnetic field, and frequency. The imaginary part of susceptibility

Superconductors (cont'd.)

exhibits a peak below the critical temperature that is attributed to hysteresis losses at the grain boundaries. There is a small shift in this coupling peak towards higher temperature with frequency increasing from 10 to 1000 Hz. We explain the shift in the context of Anderson flux creep on a scale of milliseconds at the grain boundaries. The shift is dependent on the amplitude of the measuring field. The activation energy for flux creep ranges from 11.9 eV at 0.8 $A \cdot m^{-1}$ (0.01 Oe) to 1.2 eV at 800 $A \cdot m^{-1}$ (10 Oe). We extrapolate our data to find the value for an intergrain decoupling field of 1.1 $kA \cdot m^{-1}$ (14 Oe) above which the flux creep presumably becomes flux flow. We also measured a frequency shift of the intrinsic peak of the imaginary part of susceptibility, attributed to grains, for a measuring field of 4.8 $kA \cdot m^{-1}$ (60 Oe). For lower fields, there was no observed shift in the intrinsic peak as a function of frequency.
[Contact: Martin Nikolo, (303) 497-5869]

Peterson, R.L., **Magnetization of Imperfect Superconducting Grains.**

A critical-state theory of the magnetization of superconducting grains containing nonsuperconducting regions shows that the thickness of the sheath of supercurrents around these regions can be more important than the grain dimension in determining the magnetization. This conclusion may explain some apparently conflicting results on the magnetization of powders of different sizes.
[Contact: Robert L. Peterson, (303) 497-3750]

Peterson, R.L., and Ekin, J.W., **Aria-Pattern Weak-Link Modeling of Critical Currents in Several Granular High T_c Superconductors.**

We have measured the transport critical current density at very low magnetic fields in samples of superconducting bulk sintered $Y_1Ba_2Cu_3O_x$ obtained from several sources. The results are analyzed with a statistical model which assumes that the current is limited by weak links (SNS of SIS Josephson junctions, or microbridges) whose locations are to be determined. The fitting procedure yields the average cross-sectional area of the weak links. By assuming the link thickness to be twice the London penetration depth at 77 K, we find that the average linear dimensions of the links are in all cases comparable to the grain dimensions. The quantitative analysis also confirms the percolation concept in which a subset of weakest links controls the transport current.
[Contact: Robert L. Peterson, (303) 497-3750 or 3227]

Peterson, R.L., and Ekin, J.W., **Weak-Link Modeling of Critical Currents in Several Granular High T_c Superconductors.**

The transport critical current density of a bulk sample of superconducting $Y_1Ba_2Cu_3O_x$ was measured at very low magnetic fields and fitted to a model which assumes that the impediments to current at such fields are Josephson weak links. The starting powder was made from hydoxycarbonate precursors; the final bulk sintered sample was very fine-grained, having an average grain size of about 1.8 μm as determined by a linear intercept analysis. The fit to the model is excellent if the linear dimension of the weak links is chosen to be 2.0 μm. We conclude that this sample has Josephson weak links at its grain boundaries, and any intragrain defects which may be responsible for flux pinning are not acting as Josephson weak links.
[Contact: Robert L. Peterson, (303) 497-3750]

Recently Published

Katayama-Yoshida, H., Hirooka, T., Oyamada, A., Okabe, Y., Takahashi, T.,

Superconductors (cont'd.)

Sasaki, T., Ochiai, A., Suzuki, T., Mascarenhas, A.J., Pankove, J.I., Ciszek, T., Deb, S.K., Goldfarb, R.B., and Li, Y., **Oxygen Isotope Effect in the Superconducting Bi-Sr-Ca-Cu-O System**, Physica C, Vol. 156, pp. 481-484 (North-Holland, Amsterdam, 1988).

An oxygen isotope effect is observed in mixed-phase Bi-Sr-Ca-Cu-O superconductors when ^{18}O is substituted for ^{16}O. The isotope substitution is confirmed by Raman scattering. The superconducting transition temperature T_c, measured by electrical resistivity and magnetic susceptibility, is lowered by 0.34 ± 0.03 K for the higher T_c (approximately 110-K) phase and by 0.33 ± 0.04 K for the lower T_c (approximately 75-K) phase. The results suggest a measurable contribution to the superconductivity from phonons in the two-dimensional CuO_2 planes.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Moreland, J., and Hirabayashi, H., **18th International Conference on Low Temperature Physics· (LT-18)** [Kyoto, Japan, August 20-26, 1987], Cryogenics, Vol. 28, No. 8, pp. 543-544 (August 1988).

This note discusses results presented relating to superconductivity, especially superconductivity above liquid-nitrogen temperature at the 18th International Conference on Low Temperature Physics (LT-18), held in Kyoto, Japan, August 20-26, 1987. Over 1600 persons from 36 countries attended LT-18, with papers presented in areas including superconductivity, magnetism, heavy-electron systems, density waves, thermometry, cryogenic techniques, liquid helium 3 and helium 4 and superfluid properties, critical phenomena, polarized systems, metals, and semiconductors. About 200 of the contributed papers (20% of the total) were on high-critical-temperature superconductors, and there was a special symposium on this topic.
[Contact: John Moreland, (303) 497-3641]

ELECTROMAGNETIC INTERFERENCE

Radiated Electromagnetic Interference

Released for Publication

Kanda, M., **Standard Probes for Electromagnetic Field Measurements.**

Various standard antennas for measuring radio-frequency electric and magnetic fields are discussed. A theoretical analysis of each antenna's receiving characteristics is summarized and referenced. Antennas described are an electrically short dipole, a resistively loaded short dipole and half-wave dipole, an electrically small loop, a resistively loaded loop, and a single-turn loop designed for simultaneous measurement of the electric and magnetic components of near-fields and other complex electromagnetic environments. Each type demonstrates a different compromise between broadband response and sensitivity.
[Contact: Motohisa Kanda, (303) 497-5320]

Kanda, M., **Standard Probes for Electromagnetic Interference Measurements and Their Calibration Methods.**

Various standard antennas for measuring radio-frequency electric and magnetic fields are discussed. A theoretical analysis of each antenna's receiving characteristics is summarized and referenced. Antennas described are an electrically short dipole, a resistively loaded short dipole and half-wave dipole, an electrically small loop, a resistively loaded loop, and a single-turn loop designed for simultaneous measurement of the electric and magnetic components of near-fields and other complex electromagnetic environments. Each type demonstrates a different compromise between broadband response and sensitivity. This paper also

Radiated EMI (cont'd.)

discusses the calibration techniques for these probes using standard electromagnetic fields established in transverse electromagnetic cells, waveguide cells, anechoic chambers, and open field sites. [Contact: Motohisa Kanda, (303) 497-5320]

Koepke, G.H., Ma, M.T., and Bensema, W.D., **Theory and Measurements of Radiated Emissions Using a TEM Cell**, to be published as NIST Technical Note 1326.

The transverse electromagnetic (TEM) cell is widely used to evaluate the electromagnetic characteristics of electrically small devices. This paper reviews the theoretical basis for a technique to quantify the radiated emissions from any such device in the cell. The technique is well suited to an automated test system provided that the mechanical motions required can be controlled by a computer. The difficulties associated with these mechanical motions are discussed, and possible solutions are proposed. The measurement technique is also expanded to include multiple-frequency sources in addition to single-frequency sources.
[Contact: Galen H. Koepke, (303) 497-5766]

Masterson, K.D., and Driver, L.D., **A Broadband, Isotropic, Photonic Electric Field Probe for Measurements from kHz to Above 1 GHz**, to be published in the Proceedings of SPIE, High Bandwidth Analog Application of Photonics II, (International Society of Optical Engineers, Boston, Massachusetts, September 6-10, 1988).

An isotropic, photonic electric-field meter (PEFM-15) having 15-cm resistively tapered dipole sensing elements and Pockels-effect electro-optic modulators is used to measure electromagnetic fields of 10 to 100 V/m from 10 kHz to beyond 1 GHz. The probe's frequency response is flat to within ±3 dB from 30 kHz to 100 MHz except for a region between 1 and 10 MHz where acoustic resonances occur in the $LiNbO_3$ modulator crystals. Using a 3-kHz detection bandwidth, the noise equivalent field is approximately 7 V/m, thereby giving a calculated linear dynamic range of 68 dB in field power density. The isotropic response is flat to within ±2 dB, and each individual dipole follows the theoretically predicted angular response. An optical beam switch that connects the individual dipoles to a laser source and optical receiver is also described.
[Contact: Keith D. Masterson, (303) 497-3756]

Wu, D.I., and Kanda, M., **Theoretical and Experimental Data Comparison of the Radiating Near-Field of an Open-Ended Rectangular Waveguide.**

A comparison between theoretical and experimental data on the radiating near-field of an open-ended waveguide (OEG) is presented. Two theoretical methods are examined. The first one is an approximation based on simple plane-wave equations with the electric field expressed in terms of the gain of the OEG. The gain equation is an empirical relation obtained from scaled measured data. The second approach is based on far-field to near-field transformations. Its purpose is to provide an alternate method for computing the fields as well as to provide a means of assessing the accuracy of the first approach. Theoretical data computed using both methods are presented along with measured data obtained in the anechoic chamber. The discrepancy between the two theoretical approaches is typically less than 0.5 dB, while the discrepancy between the theoretical and experimental results varies slightly depending on the distance between the OEG and the field point.
[Contact: Motohisa Kanda, (303) 497-5320]

Radiated EMI (cont'd.)

Recently Published

Adams, J.W., and Friday, D.S., **Measurement Procedures for Electromagnetic Compatibility Assessment of Electroexplosive Devices,** IEEE Transactions on Electromagnetic Compatibility, Vol. 30, No. 4, pp. 484-494 (November 1988).

Electroexplosive devices (EEDs) are electrically fired explosive initiators used in a wide variety of applications. The nature of most of these applications requires that the devices function with near certainty when required and otherwise remain inactive. Recent concern with pulsed electromagnetic interference and the nuclear electromagnetic pulse made apparent the lack of methodology for assessing EED vulnerability. A new and rigorous approach for characterizing EED firing levels is developed in the context of statistical linear models and is demonstrated in this paper. We combine statistical theory and methodology with thermodynamic modeling to determine the probability that an EED of a particular type fires when excited by a pulse of a given width and amplitude. The results can be applied to any type of EED for which the hot-wire explosive binder does not melt below the firing temperature of the primary explosive. Included are methods for assessing model validity and for obtaining probability plots, called "Firing Likelihood Plots." These statistical methods are both more general and more efficient than previous methods for EED assessment. The results provide information which is crucial for evaluating the effects of currents induced by impulsive electromagnetic fields of short duration relative to the thermal time constant of an EED. Methods of measuring the thermal time constant of an EED and the energy needed to fire an EED with a single current impulse are given. These parameters are necessary not only to determine suitable ranges in the design of the statistical experiment, but also in assessing the effect of pulses on EEDs in electromagnetic compatibility analyses.
[Contact: John W. Adams, (303) 497-3328]

Driver, L.D., and Kanda, M., An **Optically Linked Electric and Magnetic Field Sensor for Poynting Vector Measurements in the Near Fields of Radiating Sources**, IEEE Transactions on Electromagnetic Compatibility, Vol. 30, No. 4, pp. 495-503 (November 1988).

A unique, single-element antenna-sensing scheme is described which can simultaneously measure the electric, magnetic, and time-dependent Poynting vectors of electromagnetic (EM) fields. The electric and magnetic responses of the antenna sensor are separated by a 0°/180° hybrid junction. The resulting two radio-frequency voltages, along with relative phase and frequency information, are transmitted to a remotely located vector analyzer by a pair of well-matched fiber optic downlinks. The remote receiver displays: (1) the electric dipole response, (2) the magnetic loop response, and (3) the time phase difference between the two. This information is sufficient to determine the time-dependent Poynting vector. Both a theoretical analysis and a discussion of experimental measurements performed are presented, which describe the capabilities and performance of a working prototype of the antenna measurement scheme. The results demonstrate that a three-axis (isotropic) version of this system could be used to measure the near-fields of EM sources, as well as to completely describe the resultant flow of energy.
[Contact: Lanny D. Driver, (303) 497-3911]

Jesch, R.L., **Measurement of Shielding Effectiveness of Cable and Shielding Configurations by Mode-Stirred Techniques**, IEEE Transactions on Electromagnetic Compatibility, Vol. 30, No. 3, pp. 222-228 (August 1988).

The shielding effectiveness of cable

Radiated EMI (cont'd.)

configurations having different shielding arrangements and of shielding configurations that are used to terminate cable shields for helicopter wiring were measured by mode-stirred techniques. The mode-stirred measurements were taken at discrete frequencies between 200 MHz and 6 GHz. A description of the cable and shielding configurations is given along with plots of the measured shielding effectiveness data as a function of frequency.
[Contact: Ramon L. Jesch, (303) 497-3496]

Kanda, M., and Orr, R.D., **Generation of Standard Electromagnetic Fields in a TEM Cell**, NBS Technical Note 1319 (August 1988).

This paper documents the facilities and procedures employed by the National Bureau of Standards to calibrate radio-frequency electric-field probes using a transverse electromagnetic (TEM) cell. The advantages, limitations, and physical characteristics of TEM cells are presented. Impedance, field uniformity, and mode structure, critical aspects of a cell as a standard field enclosure, are discussed. The paper concludes with sections on setup and measurement procedures for users, uncertainty in the standard field, and statistical control of the calibration system. Copies of key references are included to provide ready access to the details of topics summarized in the text.
[Contact: Motohisa Kanda, (303) 497-5320]

Reeve, G.R., **Proficiency Testing for MIL-STD 462 NVLAP Laboratories**, Digest of the Electromagnetic Compatibility EXPO '88 Conference, Washington, DC, May 10-12, 1988, pp. T33.13-T33.15.

Some of the difficulties in obtaining accurate results using MIL-STD 462 test procedures are reviewed. Several measuring standard devices whose characteristics have been determined accurately are presented that could be used for verification of test results along with their application to proficiency testing for NVLAP certification.
[Contact: Gerome R. Reeve, (303) 497-3557]

Wilson, P.F., and Ma, M.T., **Techniques for Measuring the Electromagnetic Shielding Effectiveness of Materials: Part II -- Near-Field Source Simulation**, IEEE Transactions on Electromagnetic Compatibility, Vol. 30, No. 3, pp. 251-259 (August 1988).

This paper continues to discuss the topic of measurements of electromagnetic shielding effectiveness of materials by simulating a near-field source. Two specific measurement approaches, the use of a dual transverse electromagnetic (TEM) cell and the application of an apertured TEM cell in a reverberating chamber, are studied. In each case, we also consider the system frequency range, test sample requirements, test field type, dynamic range, measurement time required, and analytical background, and present data taken on a common set of materials.
[Contact: John W. Adams, (303) 497-3328]

Wilson, P.F., Ma, M.T., and Adams, J.W., **Techniques for Measuring the Electromagnetic Shielding Effectiveness of Materials: Part I: -- Far-Field Source Simulation**, IEEE Transactions on Electromagnetic Compatibility, Vol. 30, No. 3, pp. 239-250 (August 1988).

Shielding effectiveness relates to the ability of a material to reduce the transmission of propagating fields in order to electromagnetically isolate one region from another. Because the shielding capability of a complex material is difficult to predict, it often must be measured. A number of far-field source simulation measurement approaches are studied, including the use of coaxial transmission-line holders

Radiated EMI (cont'd.)

and a time-domain system. In each case, we consider the system frequency range, test sample requirements, test field type, dynamic range, measurement time required, analytical background, and present data taken on a common set of materials.
[Contact: John W. Adams, (303) 497-3328]

Conducted Electromagnetic Interference

Released for Publication

Martzloff, F.D., and Leedy, T.F., **Selecting Varistor Clamping Voltage: Lower is Not Better**, to be published in the Proceedings of the 8th EMC Symposium, Zurich, Switzerland, March 1989.

Surge protective devices, such as varistors, are applied to protect sensitive load equipment against power-line surges. The need to provide low clamping voltage, for protection of equipment with low inherent immunity, must be balanced against the risk of premature aging of the protective device, accelerating its aging. The paper describes four possible causes of such premature aging, calling for a more careful and thus more reliable application of protective devices.
[Contact: Francois D. Martzloff, (301) 975-2409]

Recently Published

Martzloff, F.D., **Coupling, Propagation, and Side Effects of Surges in an Industrial Building**, Conference Record of the IEEE/IAS Annual Meeting, Pittsburgh, Pennsylvania, October 3-6, 1988, pp. 1467-1476.

Measurements were made in an industrial building to determine the propagation characteristics of surges in the ac power wiring of the facility. The surges, of the unidirectional or the ring-wave types described in ANSI/IEEE C62.41-1980, were injected at one point of the system, and the resulting surges arriving at the other points were measured. The results show how unidirectional surges couple through transformers and produce a ring-wave component in the response of the system. An unexpected side effect of the surges, applied to the power lines only, was apparent damage suffered by the data line input components of some computer-driven printers in the building.
[Contact: Francois D. Martzloff, (301) 975-2409]

Martzloff, F.D., and Gruzs, T.M., **Power Quality Site Surveys: Facts, Fiction, and Fallacies**, IEEE Transactions on Industry Applications, Vol. 24, No. 6, pp. 1005-1018 (November/December 1988).

The quality of the power supplied to sensitive electronic equipment is an important issue. Monitoring disturbances of the power supply has been the objective of various site surveys, but results often appear to be instrument-dependent or site-dependent, making comparisons difficult. After a review of the origins and types of disturbances, the types of monitoring instruments are described. A summary of nine published surveys reported in the last 20 years is presented, and a close examination of underlying assumptions allows meaningful comparisons which can reconcile some of the differences. Finally, the paper makes an appeal for improved definitions and applications in the use of monitoring instruments.
[Contact: Francois D. Martzloff, (301) 975-2409]

Martzloff, F.D., **Tigers or Pussycats-Does Distance Make the Difference?**, BICSI Newsletter (Building Industry Consulting Service International), Vol. 9, No. 2, pp. 3-4 (October 1988).

The first of a two-part update is presented on progress at the National Institute of Standards and Technology in a study on the propagation of surges in building wiring systems. Part 1

Conducted EMI (cont'd.)

provides information on the organization of an informal consortium to sponsor the work and makes reference to an IEEE paper scheduled for presentation in September 1988. Part 2, to be submitted later, will describe further work.
[Contact: Francois D. Martzloff, (301) 975-2409]

Martzloff, F.D., **Tiger Tempering Tampers Transmissions**, BICSI (Building Industry Consulting Service International) Newsletter, Vol. 9, No. 3, p. 3 and p. 10 (December 1988).

Surge voltages were injected in the power wiring of an industrial building to determine their propagation characteristics. This injection was expected to affect only the power port of connected loads, but the data port components of two printers in that building were damaged. The proposed explanation is that surge currents in the ground return paths produced a difference in the ground references of the signal circuits, with magnitudes sufficient to damage the low-level logic components.
[Contact: Francois D. Martzloff, (301) 975-2409]

ADDITIONAL INFORMATION

DC & Low Frequency Metrology

Released for Publication

Kinard, J.R., and Cai, T-X., **Determination of Ac-Dc Difference in the 0.1-100 MHz Frequency Range**, to be published in the Proceedings of the CPEM-88 Conference, Tsukuba Science City, Japan, June 7-10, 1988.

Thermal voltage converter structures have been modeled theoretically and studied experimentally to determine their ac-dc differences in the 0.1 to 100 MHz frequency range. Estimated uncertainties for these ac-dc differences vary from 30 ppm at 1 MHz to 2000 ppm at 100 MHz.
[Contact: Joseph R. Kinard, (301) 975-4250]

Fundamental Electrical Measurements

Released for Publication

Coogan, P.C., Ricketts, B.W., Small, G.W., Cage, M.E., Dziuba, R.F., and Shields, J.Q., **Four Methods of Comparing the NML and NIST Representations of the Ohm Using Transportable 1 Ω, 10 kΩ, 10 pF, and Quantized Hall Resistance Standards.**

The laboratory or as-maintained ohm representations of the National Measurement Laboratory (NML) in Australia and the National Institute of Standards and Technology (NIST) (formerly the National Bureau of Standards) in the United States have been compared by four different methods. These methods involved the transport and intercomparison, over a 15-month time period, of six 1-Ω resistors, one 10-kΩ resistor, six 10-pF capacitors, and one quantized Hall device. The excellent agreement of the comparisons of the ohm representations Ω_{NML} and Ω_{NIST} obtained by four methods provides rigorous tests of the accuracies of 15 different measurement systems used at the two laboratories.
[Contact: Marvin E. Cage, (301) 975-4248]

Lists of Publications

Reidy, A.M., and Gibson, K.A., **A Bibliography of the NIST Electromagnetic Fields Division Publications**, NISTIR 88-3900 (September 1988).

This bibliography lists publications by the staff of the National Institute of Standards and Technology's Electromagnetic Fields Division for the period from January 1970 through August 1988. Selected earlier publications from the Division's predecessor organizations are included.

Lists of Publications (cont'd.)

[Contact: Kathryn A. Gibson, (303) 497-3132]

DeWeese, M.E., **Metrology for Electromagnetic Technology: A Bibliography of NBS Publications**, NBSIR 88-3097 (August 1988).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NIST in the period from January 1970 through the publication of this report. A few earlier references that are directly related to the present work of the Division are included.
[Contact: Sarabeth Moynihan, (303) 497-3678]

Palla, J.C., and Meiselman, B., **Electrical and Electronic Metrology: A Bibliography of NBS Electrosystems Division Publications, NBS List of Publications 94** (January 1989).

This bibliography covers publications of the Electrosystems Division, Center for Electronics and Electrical Engineering, NIST, and of its predecessor sections for the period January 1968 to December 1988. A brief description of the Division's technical program is given in the introduction.
[Contact: Jenny C. Palla, (301) 975-2220]

Walters, E.J., **Semiconductor Measurement Technology, NBS List of Publications 72** [a bibliography of NBS publications concerning semiconductor measurement technology for the years 1962-1988] (March 1989).

This bibliography contains reports of work performed at the National Bureau of Standards in the field of Semiconductor Measurement Technology in the period from 1962 through December 1988. An index by topic area and a list of authors are provided.
[Contact: E. Jane Walters, (301) 975-2050]

NEW CALIBRATION SERVICES OFFERED

The explosive growth of optical fiber use in the communications industry has resulted in a demand for calibration services. NIST's Boulder, Colorado, laboratory now offers **measurements of optical laser power and energy at wavelengths and power levels of interest to fiber optic producers and users.** Measurements are based on a standard reference instrument called the C-series calorimeter. An electrically calibrated pyroelectric radiometer (ECPR) is calibrated against the calorimeter and is then used to calibrate optical power meters at wavelengths of 850, 1300, and 1550 nanometers. To improve calibration capabilities, NIST is preparing test measurement systems for detector linearity, detector uniformity, and detector spectral responsivity. These systems should be available in 6 months. For a paper outlining NIST's optical power measurement capabilities, contact Fred McGehan, Div. 360, NIST, 325 Broadway, Boulder, Colorado 80303. For more information on calibration services, contact Thomas R. Scott, Div. 724, same address, or phone 303/497-3651.

R&D 100 AWARD WINNER

Image-Preserving Optical Delay

Edward F. Kelley of the Electrosystems Division is the recipient of an R&D 100 Award in 1988 for generating a pioneering photographic "time machine" which, when used with a high-speed camera, permits photographing events which occurred before the camera's shutter is opened.

The system, called an image-preserving optical delay, differs from conventional photography which records an event only when the shutter is open.

This new device, an arrangement of optical components including mirrors and

Image-Preserving Optical Delay (cont'd.)

a crystal shutter, allows researchers to take detailed, high-speed photographs of random, that is, nontriggered, events.

It is now used for processes which last from 100 ns to 10 μs to study materials utilized by the electric power industry.

This system stores optical images of a random event long enough so the shutter of a high-speed camera can be opened and photographs taken of the processes leading to the random event. Kelley has filed a patent application on the system.

Functionally, the optical delay is equivalent to forcing the image to travel an additional 120 m before it gets to the camera. Using a series of concave and planar mirrors, this path length is folded into about 4 m.

The system is rugged enough to be used in a variety of settings. Normal vibration, air currents, and airborne dust have minimal effect on its operation.
[Contact: William E. Anderson, (301) 975-2423]

RECENTLY ISSUED STANDARD REFERENCE MATERIALS

The Semiconductor Electronics Division announces the release of a new Standard Reference Material (SRM) for **ellipsometrically derived thickness and refractive index of a silicon dioxide film on silicon**. Available for sale to the public through the NIST Office of Standard Reference Materials [for orders, (301) 975-6776], SRM 2530 is separately available for three oxide thicknesses: 50 nm (2530-1), 100 nm (2530-2), and 200 nm (2530-3).

This SRM was developed to respond to industry needs to evaluate the accuracy of ellipsometers, but may also be used as aid in the calibration of various other optical and mechanical thickness monitoring instruments.

Each SRM consists of a 76-mm (3-in.) diameter silicon wafer on which a uniform silicon dioxide layer was grown, patterned, and partially covered with chromium. The certified values were determined from measurements made using the highly accurate ellipsometer developed in the Division and are the ellipsometric parameters delta, Δ, and psi, ψ, at a wavelength of λ = 632.8 nm. The SRMs are also certified for the derived values of thickness and refractive index of its silicon dioxide layer determined by using a two-layer model consisting of a silicon dioxide layer on a thin silicon-rich oxide interlayer. [Contact: Deane Chandler-Horowitz, (301) 975-2084]

1989 CEEE CALENDAR

June 12-15, 1989 (Gaithersburg, MD)

International Conference on Narrow Gap Semiconductors and Related Materials. Jointly sponsored by the National Institute of Standards and Technology, the U.S. Air Force Office of Scientific Research, the American Physical Society, National Science Foundation, the U.S. Office of Naval Research, Texas Instruments, and the University of North Texas, this conference is the first in the narrow gap field since 1981. The scope of the conference includes such topics as crystal growth and new materials; two-dimensional physics; surfaces and interfaces; superlattices and heterostructures; transport; impurities and defects; optical properties; nonlinear optical effects; device physics; lattice properties; and hot or nonequilibrium carrier effects.
[Contact: David G. Seiler, (301) 975-2081]

September 11-13, 1989 (Garmisch-Partenkirchen, FDR)

VLSI and GaAs Chip Packaging Workshop. The IEEE CHMT Society and the National Institute of Standards and Technology

CEEE Calendar (cont'd.)

are co-sponsoring the Eighth VLSI Packaging Workshop. Topics to be CEEE discussed include VLSI package design; integrated package design; multichip module design; WSI packaging; package thermal design; package electrical design; GaAs IC packaging; VLSI package interconnection options; VLSI package materials and die-attach solutions; and failure mechanism and quality of VLSI packages. All attendees are expected to be specialists working in the field and to participate in discussions.
[Contact: George G. Harman, (301) 975-2097]

December 10-11, 1989 (Gaithersburg, MD)

Power Semiconductor Devices Workshop, This Workshop, sponsored jointly by IEEE and NIST, is intended to bring together for interactive participation those actively working in the field of power semiconductor devices. It will be held in conjunction with the 1989 IEEE International Electron Devices Meeting in Washington, DC. Four specific topic areas have been selected: power and high voltage integrated circuits, discrete devices, device and circuit simulation, and packaging. In addition, a special panel on power electronics education will be held. This year's Workshop will specifically solicit attendance from device and circuit users as well as device researchers. Attendees are expected to be prepared to contribute to the development of responses to specific questions that arise in the context of the particular topic areas; a final schedule should be available at the end of October.
[Contact: David L. Blackburn, (301) 975-2068]

February 6-8, 1990 (Phoenix, AZ)

IEEE Semiconductor Thermal and Temperature Measurements Symposium. This sixth annual **SEMI-THERM** symposium is sponsored by the Components, Hybrids, and Manufacturing Technology Society of IEEE in cooperation with NIST and constitutes an international forum for the presentation of new developments relating to generation and removal of heat within semiconductor devices, measurement of device temperatures, and the simulation of device and system thermal behavior. Major SEMI-THERM topic areas include thermal measurements; thermal characterization; applications; and simulation, computation, and software.

The program includes keynote speakers, technical presentations, tutorial sessions, workshops, and an exhibit. In addition, the Semiconductor Equipment and Materials Institute (SEMI) and the Joint Electron Devices Engineering Council (JEDEC) have scheduled in conjunction with SEMI-THERM several Standards Committee Task Force meetings, to which attendees are invited.
[Contact: David L. Blackburn, (301) 975-2068]

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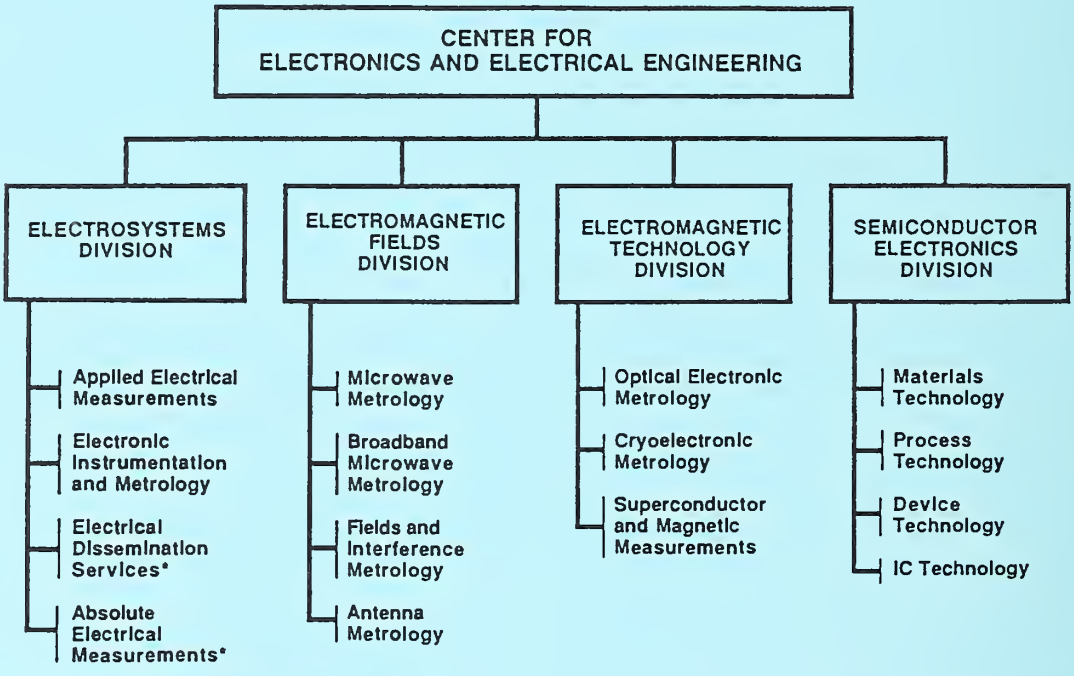

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KEY CONTACTS:

Center headquarters (720)	Director, Mr. Judson C. French (301) 975-2220 Deputy Director, Mr. Robert I. Scace (301) 975-2220
Electrosystems Division (728)	Chief, Dr. Oskars Petersons (301) 975-2400
Electromagnetic Fields Division (723)	Chief, Dr. Ramon C. Baird (303) 497-3131
Electromagnetic Technology Division (724)	Chief, Dr. Robert A. Kamper (303) 497-3535
Semiconductor Electronics Division (727)	Chief, Mr. Frank F. Oettinger (301) 975-2054

INFORMATION:

For additional information on the Center for Electronics and Electrical Engineering, write or call:

Center for Electronics and Electrical Engineering
National Institute of Standards and Technology
Metrology Building, Room B-358
Gaithersburg, MD 20899
Telephone (301) 975-2220